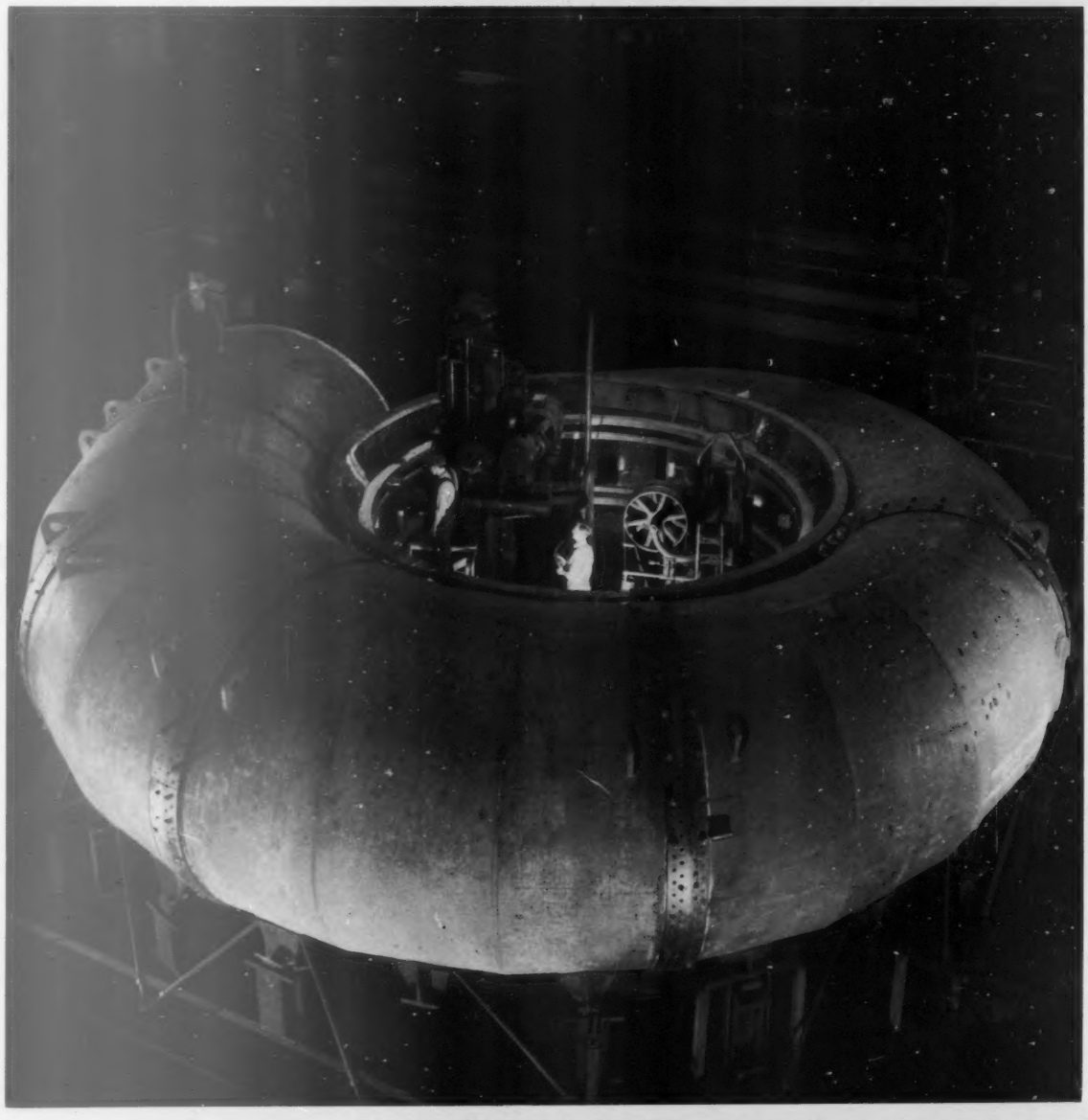
ALLIS-CHALMERS

Electrical Review



Second Quarter, 1948

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The same 1 pound pressure in a toy balloon . . . is all that's in *Oil-Sealed* Inert Gas System for Allis-Chalmers Transformers!

NO OTHER TRANSFORMER inert gas system operates at such low pressure. And to you that can mean — safety, low pressure on gaskets — low gasket maintenance!

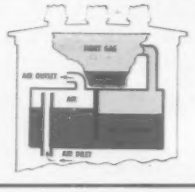
In addition, the system is tops for simplicity! It has no moving parts; no sensitive gauges or reduction valves; it doesn't require periodic replenishment of nitrogen; no bottles to buy!

Originated by A-C in 1923, this system is now standard for over 5,000,000 kva of U. S. Power! For more information call your nearby A-C sales representative, or write ALLIS-CHALMERS, MILWAUKEE 1, WISCONSIN. *Oil-Sealed* is an Allis-Chalmers trademark.

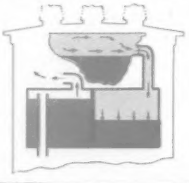
A 2497

SIMPLE AS A-B-C

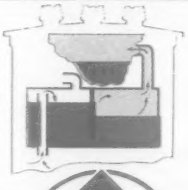
A PRINCIPLE — Transformer cooling oil is isolated from the atmosphere by inert gas and oil seal. This prevents sludge formation and fire hazard due to oxygen. By excluding moisture the system maintains high dielectric quality of oil.



B AS TRANSFORMER HEATS, the cooling oil expands, displacing inert gas from main tank to auxiliary tank. The transfer of gas to the auxiliary tank is cushioned by the change in oil levels as shown, keeping the main tank pressure low.



C AS TRANSFORMER COOLS, the reverse takes place.. In this simple manner inert gas protection is provided automatically . . . transformer oil adjusts itself to changing temperatures without being exposed to the atmosphere.



ALLIS-CHALMERS

Originators of the "Oil-Sealed" Inert Gas System!

MACHINING SPEED RING for this giant spiral casing for the fifth Shasta Dam hydraulic turbine reflects a departure from usual shop practice. Because its diameter was too great for the revolving table of the 40-foot boring mill, the casing was set on steel supports and the cutter was rigged to the table to travel around the inner 18-foot diameter of the ring.

Casing consists of seven welded sections with riveted buttstrap joints. The inlet, facing wall at left, is made of 1⅞-inch plate, and has an inside diameter of 12 feet 8 inches. Four Allis-Chalmers turbines, rated 103,000 hp at 138½ rpm under 330-foot head, are already installed at Shasta.

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Allis-Chalmers

Electrical Review

Vol. XIII No. 2

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ALLIS-CHALMERS Electrical REVIEW

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THIS PREVIEW of the year ahead for the electrical industry by the 1947-48 President of the National Electrical Manufacturers' Association was delivered before the Engineers' Club of St. Louis recently. Because of its special significance, the "Review" is pleased to reproduce this condensation of the original presentation.

The Electrical Industry LOOKS AHEAD

W. C. JOHNSON
Executive Vice-President
Allis-Chalmers Mfg. Co.

SINCE the successful experiments with nuclear fission as a destructive force, many an armchair commentator has referred to our time as the "ATOMIC AGE." Nonsense!

Let's be a little more realistic. I'd like to take these "ages" in proper order and one at a time. When we do that we can better put our minds to the full "ELECTRICAL AGE" which we are about to enter. Oh sure, I know that electricity has been in use since Joule and Watt, and in ever increasing use since Edison, but I also know that iron was made for thousands of years by charcoal, until Dud Dudley, in the early 17th century, developed a practical method of making it with coal and coke.

Just as our early forefathers had been dawdling with the making of iron in charcoal braziers for foundries, so have we relatively been groping our way into the use of electricity, and I think that we have only begun to scratch the surface of its maximum use in this great land of ours.

In every part of the electrical industry, whether our job is selling kilowatts, designing X-ray machines, or calculating transmission line losses, the year ahead should be a shining one for all of us. Because of conditions, our programs are scheduled well in advance. For most of us, the business picture is both clear and optimistic. For some of us in the heavy apparatus business, the rosy future is even more enduring.

Therefore, with our tasks assigned to us and our immediate future assured, perhaps this is the time for all of us to spend our spare moments doing some thinking and planning for the future. Is the present rush to buy, to build, and to extend, just a "spurt," or will it continue and for how long?

Now, I don't profess to be an oracle or a seer in this business and I know that some of the following observations are open to challenge. Perhaps, though, they may be of some help toward additional thinking by those of you who are much closer than I to the "front line" where kilowatts become light and heat and horsepower.

Many of us, absorbed in our everyday life, have lost account of the changes taking place around us. So often we hear utility men remark: "We simply don't know where all the load on our system is coming from." And because it is good business for our company, I generally answer, "Hold onto your seat, mister, you ain't seen nothing yet!" Many of the sources of these loads that are already burdening power systems are today in but the most rudimentary pilot stages of development.

Much of the American public thinks of electricity in terms of electric lights, simple domestic appliances, or perhaps an electric motor or two here and there. To appreciate what is before us, however, we must think in terms of entirely electrical chemical plants, of completely electrical oil refineries, and of many other fields where the broadening use of electric power will continue to add burden to power systems for years to come. Some of the recent applications of radio frequency in chemical and oil refining processes have startled even the discoverers themselves. Arc furnaces for melting are already old stuff, but radio frequency heat for melting, tempering, normalizing, or joining metals is just in its infancy.

* * *

Atomic age? No! We are only entering a fully electrical age. I think I am correct in stating that the nearest approach

to control of power from nuclear fission today is its use as a heat source or a substitute for coal, and I don't think that John L. Lewis will live long enough to raise the price of coal to the point where power piles will become competitive.

Up to now we have been discussing the part the electrical industry is taking in industry itself, but if we want to see some real big changes let's get down to the grass roots — let's talk about the use of electricity in the home.

To be real practical, let's go back to 1938 instead of 1913. Now, 1938 was not so very long ago. Most of us thought of 1938 as a part of the depression. However, time and the events of the recent past have mellowed us a little and, probably because of the present cost of a good steak, we look back on 1938 as part of the "good old days."

Ten years ago nearly all of us had electric lights, radios, toasters, washing machines, and the other usual appliances in our home. And since most of us have some intimate acquaintances with housing shortages, I think we will all agree that we had almost as many houses as we have today. In 1938 the residential use of power was approximately 19,000,000,000 kw-hours. In 1948, the forecasted use is at least 45,000,000,000 kw-hours, almost 2½ times as much power in 10 years! No wonder that our power plants are running within 5 percent of capacity over the nation.

Ten years ago, home air-conditioning, home freezers, automatic washers, electrically-heated clothes dryers, and many such appliances were little heard of. Today, most folks look forward to the day when they can use them.

Add to this list the use of electricity on farms — the same farms that we think of when we picture in our minds the source of all America's food — the white frame house, its red barn, a garage and shed, and a few buildings scattered around the road going past the door. Ten years ago, only a few farmers had the advantages that we urban dwellers had learned to accept as necessities. Today, well over half of them have power lines alongside the road. The yellow lamp light has been replaced with bright incandescent lights and the old farm lantern may soon be relegated to museums.

What about the future?

Thus, the whole way of America's living and working is going through a change, and unless something happens to kill off "Yankee ingenuity," it is not going to stop changing, either.

What about the future? Being in the electric apparatus business, my mind turns first to thinking of industrial applications. The war made some real changes in our thinking about designs and it brought with it many developments in material that enabled our engineers to plan and build for future applications. There are going to be smaller and lighter weight motors, generators, and transformers.

There is a long list of developments in mobile substations, in mobile capacitor banks, and mobile power plants ready to move on emergency call in any direction. No one so far has asked us to build a flying sub-station, although flying television stations are being tested by one manufacturer!

Induction heating will continue to be a big factor in the use of electricity. Single heaters rated at more than 100 kw are now rather common. I understand that an RF heater with a short time rating of 5000 kw has already been tried.

Who knows how many more such applications will be presented to add to this great industry, the common denominator of all business and home life?

Switchgear and power circuit breakers are going through the process of growing in two directions at one time. Circuits are becoming more complex with elaborate interlocking and control features, but the breakers themselves are becoming simpler.

New problems will arise

Now if my vision is clear and this industry is destined to grow as I think it will — it will not be all a bed of roses. Problems will present themselves which will tax the best of our thinking.

Today we buy many things from many people and, because we are in daily contact with them, they are real human beings to us. When these services come to us over the wires from but a single source and we receive the bill through the mail — it becomes more and more an impersonal relationship subject to increasing pressure and socialization.

As more and more of our life depends upon power, it must be made more and more dependable, and in the event of possible war it must be even more dependable. Thus it must be more thoroughly interconnected. Furthermore, utilities should be planning together now for broad scale cooperative efforts in the industry to meet conditions of emergency. As one of the nation's most vital industries, we have a solemn responsibility in our national defenses.

I think, in view of the international situation, common sense dictates the immediate formation of an Electric Power Industry Advisory Group along the lines suggested by Mr. Walker L. Cisler of the Detroit Edison Co. at the AIEE General Winter Meeting in Pittsburgh late in January.

Any industry planning group will have, of course, a vital interest in the developments of nuclear energy. Power suppliers must be kept informed as much as national security will permit, of the progress made in this potent heat source.

* * *

Well, gentlemen, a good share of nineteen hundred and forty-eight has already gone by. It's a year of action and wonderful opportunity. If it ever was, our future — and in many ways the future of America as we know and love it — is in our hands. We can go along completely oblivious to our responsibilities for the common good. We can make all the money we can, regardless of what the public — that's our friends, you know — regardless of what they think. We can forget to vote, or figure that voting doesn't matter. We can cuss Congress and damn the unions like some other industries have done. Maybe we can do all these things — and think we're getting by — but I don't think so.

I think that if we're really sincere, if we love the priceless heritage of living in America, we'll do a lot of honest thinking in 1948, a lot of self-examination — a lot of planning. Maybe we ought to do a lot of voting, too — and see that everyone we know does the same.

If we do, the day will come when you and I and all of us can look back and really mean it when we say, "Nineteen-forty-eight, boy, those *were* the good old days!"

Reheating *Comes back*

Operating costs, greater thermal gains favor reconsidering the reheat cycle.

C. W. BLOEDORN
Steam Turbine Dept.
Allis-Chalmers Mfg. Co.

THE REHEAT cycle is once again coming into serious consideration in new steam turbine installations. Revived interest at this time is due to the great increase in fuel costs and the consequent attempt to improve operating efficiencies above that attainable with the straight regenerative cycle and today's limits in steam conditions. It is interesting to note that while in most cases today the prime objective in considering the use of the reheat cycle is the possible gain in the thermal efficiency, reheating was not originally considered as a direct means of achieving this goal.

In the early installations, made about 20 years ago, reheat was used to reduce the moisture content at the turbine exhaust in order to minimize blade erosion. This, in turn, permitted the use of higher throttle pressures at the maximum steam temperatures then allowable with a consequent gain in thermal economy. A curve, such as shown by Figure 1, often was used as a guide to determine whether or not reheat was advisable from the standpoint of reducing moisture content of the steam in the low pressure stages. If the steam conditions selected resulted in a moisture content less than 12-13 percent, there was a feeling among a large number of users that the added complication and cost of a reheat installation was not justified.

Factors affecting popularity

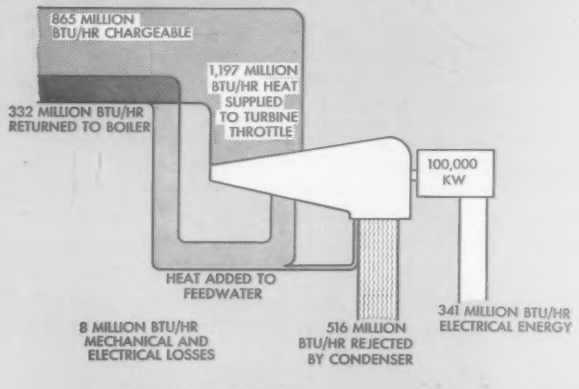
In addition, many engineers were not ready to adopt the unit arrangement of one boiler per turbine which is so well suited to the use of reheat. Until the pressure of rising fuel costs was felt recently, less attention was given to the use of reheat and more attention was given to increasing thermal efficiency through improvements in the regenerative cycle, through the use of topping turbines and through the use of the maximum practical pressures and temperatures. The topping turbine filled a special requirement and there were a considerable number of turbines of this type installed in the late 1930's, but because of its limited application very few topping turbines have been installed in the past few years.

Also, in the 1930's, considerable progress was made in the use of the regenerative feedwater heating cycle. The use of four or five stages of feedwater heating in central station turbines became quite commonplace and, in some cases, six and even seven stages were used.

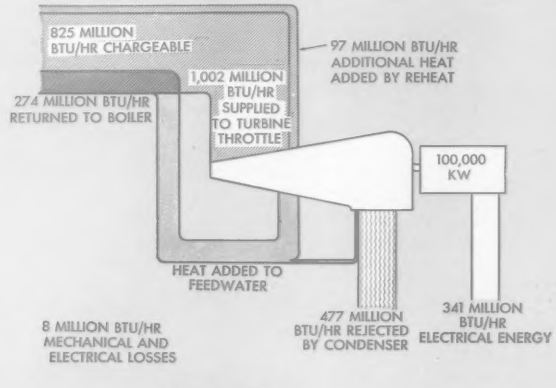
In the past fifteen years metallurgical developments have permitted a steady increase in allowable steam temperatures. With the gain in thermal economy obtained through the use of higher initial temperatures, it was felt that the additional cost and complication of reheat was not justified. However, with the present high prices of fuel, consideration is being given not only to the use of the maximum practical steam temperature but also to the combination of reheat with high pressures and temperatures. Consideration is being given to reheat even though the point locating the throttle pressure and temperature may fall in the area below the curve shown in Figure 1.

Unit arrangement cuts initial cost

During the past few years, there has been a definite trend toward the wider use of the single boiler, single turbine arrangement because of the proven high availability of modern boilers and because of the necessity for keeping initial costs as low as possible. The adoption of this arrangement overcomes some of the objection to the reheat cycle, which, for minimum complication, requires a single boiler per turbine. Further, to combat arguments against reheating because of operating difficulties, power plants which have been using the reheat cycle for many years have reported no serious difficulties encountered in service. Reheat turbines have been put on and

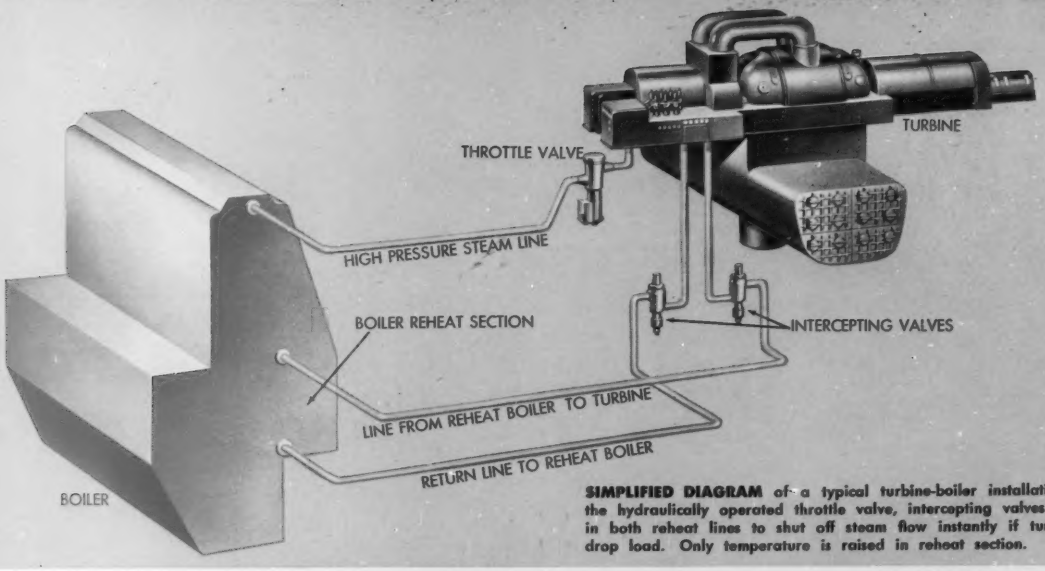

865 MILLION BTU/HR CHARGEABLE
1,197 MILLION BTU/HR HEAT SUPPLIED TO TURBINE THROTTLE
332 MILLION BTU/HR RETURNED TO BOILER
100,000 KW
HEAT ADDED TO FEEDWATER
8 MILLION BTU/HR MECHANICAL AND ELECTRICAL LOSSES
516 MILLION BTU/HR REJECTED BY CONDENSER
341 MILLION BTU/HR ELECTRICAL ENERGY

NON-REHEAT TURBINE


825 MILLION BTU/HR CHARGEABLE
97 MILLION BTU/HR ADDITIONAL HEAT ADDED BY REHEAT
1,002 MILLION BTU/HR SUPPLIED TO TURBINE THROTTLE
274 MILLION BTU/HR RETURNED TO BOILER
100,000 KW
HEAT ADDED TO FEEDWATER
8 MILLION BTU/HR MECHANICAL AND ELECTRICAL LOSSES
477 MILLION BTU/HR REJECTED BY CONDENSER
341 MILLION BTU/HR ELECTRICAL ENERGY

REHEAT TURBINE

GAIN IN EFFICIENCY by using reheat is clearly shown in these heat flow diagrams of comparable 100,000-kw turbo-generator installations. Both have the same radiation, friction and condensate heat losses. In addition, both have identical original steam pressures and temperatures.



SIMPLIFIED DIAGRAM of a typical turbine-boiler installation. Besides the hydraulically operated throttle valve, intercepting valves are placed in both reheat lines to shut off steam flow instantly if turbine should drop load. Only temperature is raised in reheat section.

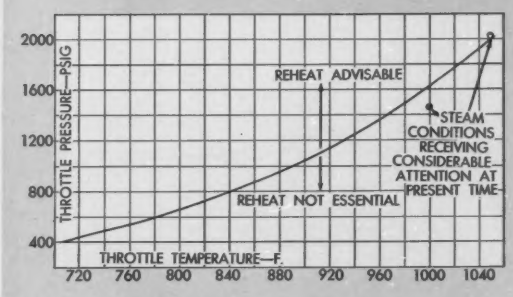
taken off the line as required by the load conditions with no greater difficulty than with non-reheat machines.

One objection raised in the earlier years to the reheat machines was the large volume of steam entrained in the reheat lines which might cause overspeeding in case of loss of load. Today, reheat turbines are provided with intercepting valves in the line going to and from the turbine to the reheat boiler. These intercepting valves are under control of the main speed governor and are arranged to close if the speed of the unit increases to approximately four percent above normal. This arrangement has proved to be an entirely satisfactory solution to the overspeed problem without causing undue complication of the turbine governor gear. Reheat turbines, incidentally, have been used successfully for ship propulsion service as well as for central station service.

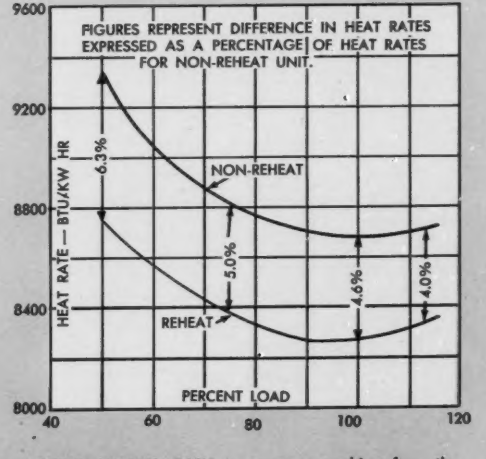
Various estimates have been made which indicated that the gain in economy due to reheating varies from about four to six percent. Figure 2 gives a comparison of heat rates in BTU/kwhr for a typical 100,000-kw non-reheat turbine unit and a similar size reheat unit. Throttle steam conditions in each case were 1,250 psig, 950° F and the exhaust vacuum 28½ inches. The feedwater heating cycle was the same in either case. The steam was reheated to 950° F for the reheat turbine. The analysis of the economics for such an installation is too long for treatment here, and it must take into consideration initial cost, fuel cost, load factor, reliability, operating convenience, and many other variables. Typical analyses which have been made, however, show that this thermal gain may offset the additional cost and complicating factors.

Studies disclose best reheat pressure

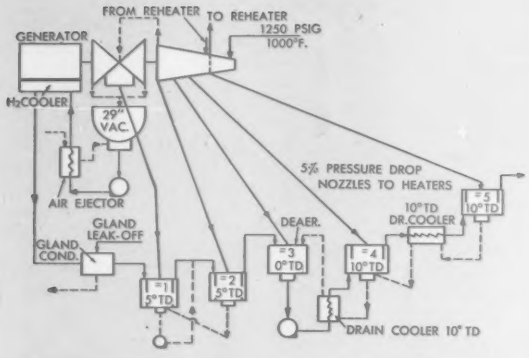
In order to determine the most desirable pressure at which to reheat the steam, from the standpoint of the turbine and its feedwater heating cycle, calculations were made based on a rating of 120,000 kw and with steam conditions of 1,250 psig, 1,000° F at the throttle, reheat to 950° F and exhaust at 29-inch vacuum. The calculations were based on the feedwater heating cycle as shown schematically by Figure 3. This sketch does not necessarily illustrate a recommended arrangement, but merely indicates the cycle used for convenience in obtaining relative results for comparison purposes. Steam for the high pressure heater in each case was extracted from the turbine



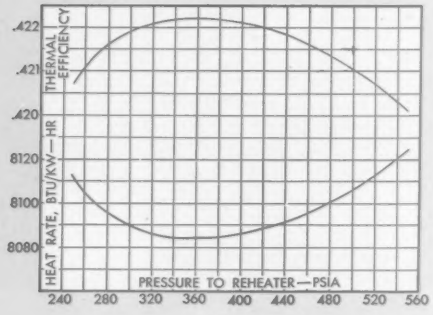
TYPICAL CURVE used in the past to determine whether or not reheat was advisable from standpoint of moisture content at exhaust. **(FIGURE 1)**



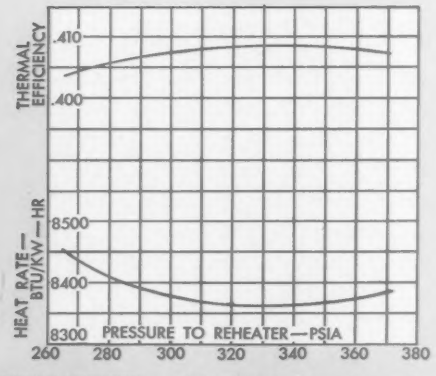
CURVE SHOWS GAIN in economy resulting from the use of reheat and indicates how the improvement varies with load on the turbine. **(FIGURE 2)**



FEEDWATER HEATER arrangement shown above was used as a basis in calculating the results shown in Figure 4. The feedwater heating cycle shown does not necessarily represent a recommended cycle. **(FIGURE 3)**



THERMAL EFFICIENCY differs slightly for a wide range of reheat pressures. A series of calculations revealed that the most economical reheat pressure for conditions specified is 365 psia. **(FIGURE 4)**



REHEAT PRESSURE analysis charted above was made for an 80,000 kw steam turbine actually designed to give a reheat pressure of 329 psia at the load point studied. Reheat temperature was 850 degrees F. **(FIGURE 5)**

at the reheat belt before going to the reheat boiler. Some check figures indicated that an extraction opening above the reheat point was not practical for this throttle steam pressure, especially if an economizer was used.

Figure 4 shows graphically the results of the study to determine the most efficient reheat pressure for this rating. It can be seen that the variation in heat rate over the entire range in reheat pressure considered is only in the magnitude of a fraction of one percent. The results indicate that from the standpoint of the turbine and its feedwater heating cycle, the most efficient reheat pressure for the steam conditions used is in the neighborhood of 365 psig. Since the reheat pressure can be varied considerably without an appreciable change in turbine heat rate, other factors such as piping and valve sizes or boiler performance may indicate a higher or lower pressure to be more economical from the over-all plant standpoint. This data checks satisfactorily with pressures, or the throttle and reheat pressure ratio used on existing machines.

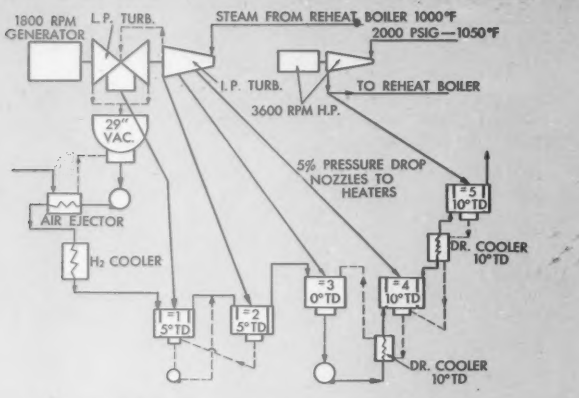
Figure 5 shows the results of a similar study made for an 80,000-kw turbine designed for throttle steam conditions of 1,290 psig, 850° F and 850° F reheat temperature. This machine actually was built to give a reheat pressure of 329 psig at the load point for which the analysis was made.

At the present time consideration is being given to the use of large reheat turbines designed for throttle steam conditions in the range of 2,000 psig and 1,050° F and reheating to 1,000° F. Figure 6 shows schematically the feedwater heating cycle used in making a reheat pressure analysis for a 120,000-kw steam turbine unit designed for the above steam conditions. As shown schematically, units of this type for this size and larger, and designed for steam conditions in this range, are of the cross-compound type. The high pressure, 3,600-rpm turbine exhausts the steam to the reheat boiler and to the high pressure feedwater heater. The steam from the reheater is expanded in the intermediate pressure section down to about 25 psig and then exhausted to the double flow low pressure turbine which is in tandem with the intermediate pressure element and operates at 1,800 rpm.

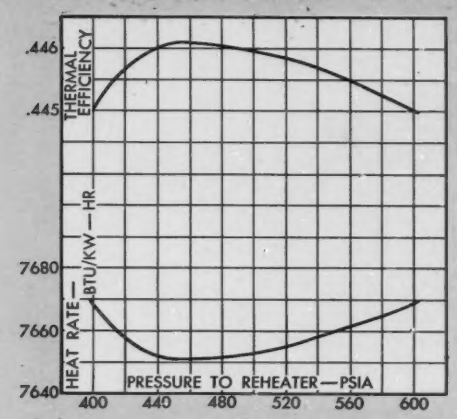
Figure 7 shows graphically the results of the study to determine the most efficient reheat pressure for such an installation. Again, the variation in turbine heat rate over the entire range of pressures selected is in the magnitude of a fraction of a percent. The curves indicate a most efficient pressure of about 460 psig for the turbine and its feedwater heating cycle.

Reheat pressure affects generator size

In addition to giving consideration to valve and pipe sizes and boiler performance in determining the most economical reheat pressure from the over-all standpoint, with the cross-compound type of turbine, the size of the generators also depends on the reheat pressure which is the exhaust pressure of the high pressure turbine. Figure 8 shows the output of the high pressure 3,600-rpm element expressed as a percentage of the total output at different exhaust pressures for this element. While this curve was plotted from calculations made for the 120,000-kw rating, the curve can be used to obtain closely approximate figures for larger ratings operating with the same steam conditions. Inasmuch as the reheat pressure can be varied considerably without greatly affecting the efficiency, a reheat pressure may be selected to give standard ratings for the two generators.



THIS FEEDWATER heating cycle arrangement was used in reheat pressure analysis for a large cross-compound turbine unit. High pressure turbine operates at 3,600 rpm, intermediate and low pressure at 1,800. **(FIGURE 6)**



RESULTS OF STUDY to determine the most economical reheat pressure for a cross-compound turbine unit reveal that, for conditions selected, most efficient reheat pressure proved to be 460 psia. **(FIGURE 7)**

In obtaining the results shown in Figure 7, steam for the highest pressure heater was taken from the exhaust of the high pressure turbine. With the cross-compound arrangement, space is available for providing an extraction nozzle on the high pressure turbine at a point giving a pressure higher than the reheat pressure, and another heater can be added to the feedwater heating cycle.

A study of this arrangement indicates that the turbine heat rate can be reduced approximately 0.6 percent by adding a higher pressure heater to the cycle shown in Figure 6 and bleeding from a nozzle located in the middle of the high pressure cylinder. Whether or not the over-all plant economics justify this higher pressure extraction is something that must be analyzed in each individual case. If an economizer is used, the higher pressure heater probably cannot be justified, but some power plant engineers are giving serious consideration to these extremely high extraction pressures.

Figure 9 shows the results of the study to determine the most efficient reheat pressure when a heater is used at a pressure higher than the reheat pressure. The final feedwater temperature was not held constant in this study, but was varied so that an approximately equal rise would occur in the highest pressure heater in each case.

In this, as in all of the calculations made to obtain data for the curves showing reheat performance, a 10 percent pressure drop was taken in the reheat lines and reheat boiler.

The problems of the steam plant designer are more complex than ever today, since not only have fuel costs increased but construction and equipment costs have also jumped in varying proportions. Further increases in pressure and temperature with the straight regenerative cycle have reached the point of diminishing returns. In this new light, designs making use of the reheat cycle are being reconsidered.

Naturally, reheating is not the answer to all the problems of reduction in the cost of power generation, but there are a number of cases where the additional cost of a reheat installation can easily be justified. The author hopes that the data presented here may be of some assistance in future studies made to determine whether or not reheat is justifiable.

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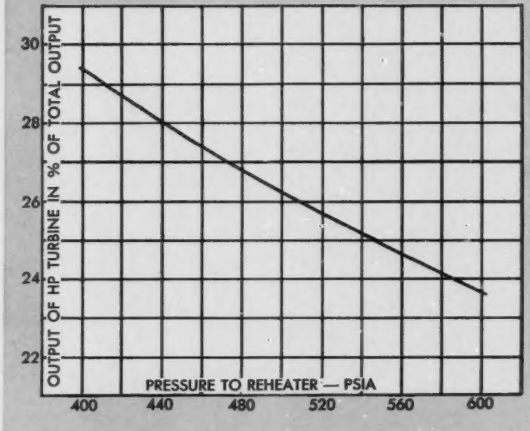
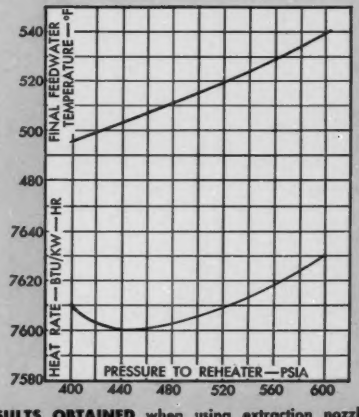
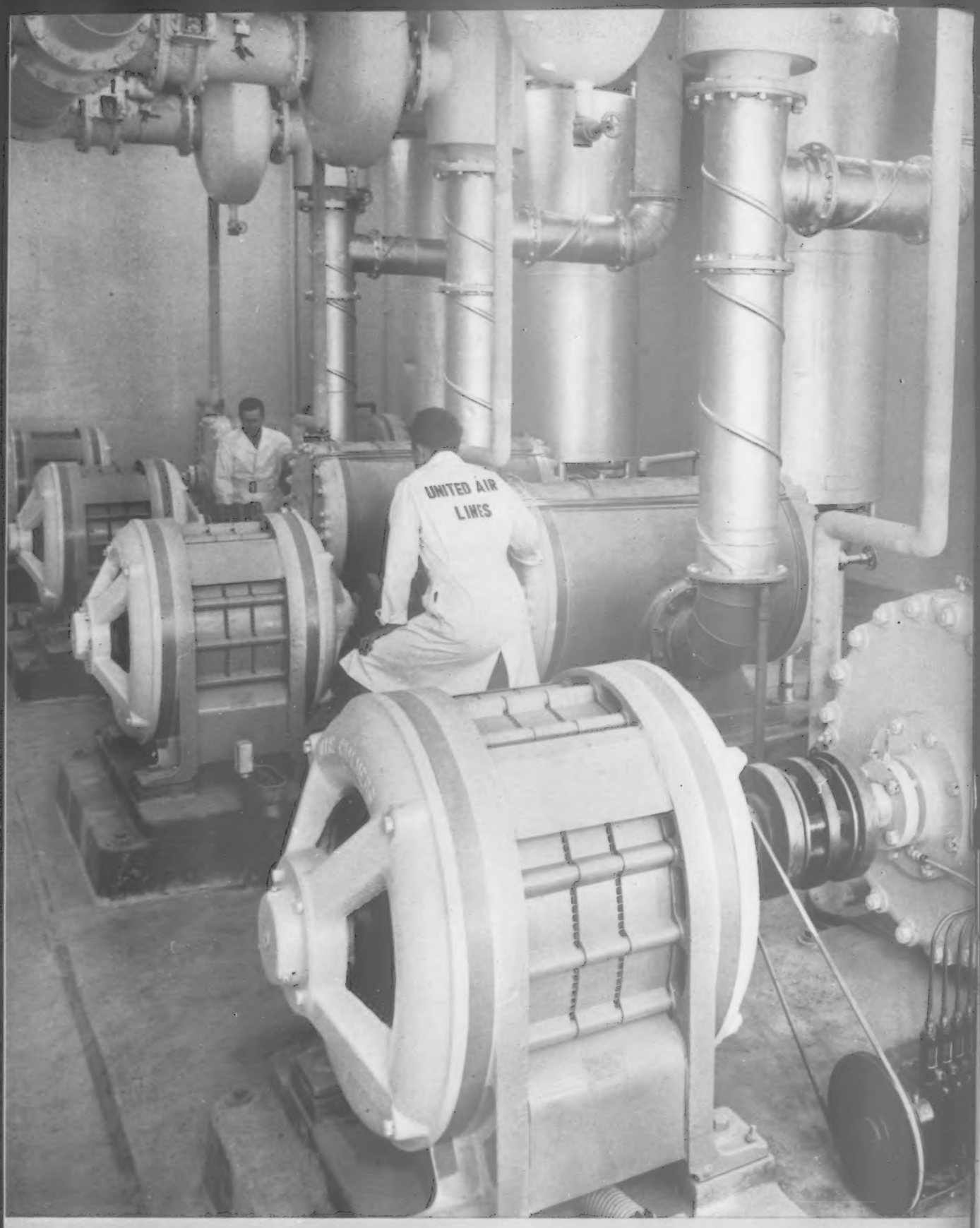


APPROXIMATE OUTPUT of a 3,600-rpm, high pressure cross-compound turbine at full load and at various heat pressures. In this case, size of generators is influenced by pressure to the reheater. **(FIGURE 8)**



RESULTS OBTAINED when using extraction nozzle located a few stages above reheat point. If justified by plant economics, this higher pressure point can be provided with the cross-compound arrangement. **(FIGURE 9)**



SQUIRREL CAGE INDUCTION MOTORS are as vital to airline operation as planes. Connected to vacuum tanks, these 125-hp electric motors drive decompression pumps for testing carburetor performance at simulated altitudes up to 50,000 feet at a large West Coast maintenance base. Motors represent only a small part of the more than 80 tons of equipment used to test carburetors for large airliners.

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DESIGN of Work Coils

PART TWO OF TWO PARTS

BEN H. GRIFFITH, JR., and RAY SKIBA
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Allis-Chalmers Mfg. Co.

Short cuts to practical work coil design eliminate much of the confusion that confronts designers.

THE THEORETICAL calculations leading to the design of a work coil were given in Part I of this article. As we pointed out, the material is used as a basis upon which a practical and efficient work coil is designed and built: the principles remain the same, no matter how we approach the problem. The calculations themselves usually prove too complex to use in the workshop.

This portion of the article will describe the practical mechanics involved in coil construction and methods that can be used in arriving at a final coil design. Although the speed with which a properly designed coil can bring a mass of metal up to temperature may often seem like magic, the coil builder need not be a magician.

Job needs influence coil construction

The purpose of the coil is to transfer the energy from the induction heater to the work itself. To do this, it must, first of all, be efficient. The leads must have as little impedance as possible. These requirements can be partially met by keeping the leads from the coil as close together as possible, and by keeping the current-carrying surface at a maximum. The connection surfaces must be clean and bright with a maximum contact area.

It must be remembered that work coils are used in the shop where production is the main consideration. Therefore, they must be constructed to give maximum production from the heater. In addition, they must be mechanically strong, so they are not easily broken or deformed. Even slight changes in shape can greatly affect the efficiency of some coils.

The design of work coils from a practical viewpoint will be outlined below. The metallurgical treatment of the problem is not included. The quench used in treating of metals determines to a great extent the quality of the product. The design of proper quenching equipment is a complete problem in itself, especially when combined with induction heating for the treatment of steels.

Tables are available giving the watts per square inch values for many common induction heating applications, but they are difficult to use, except as a guide after some experience has been gained in coil building. However, a sample coil should be built and tried. This coil should be as simple as possible, but built with enough care so that the results will be a true indication of the design characteristics. After tests have been run, the results must be interpreted. The following interrelated aspects must be considered.

1. Degree of loading of machine
2. Amount of power available with respect to the amount of metal to be heated
3. Rate of heating of piece
4. Number of pieces to be heated at one time.

As in most equipment the most economical load for a heater is the rated load. The induction heater, because it is most efficient at or near rated output, and because the cost is based upon rated output, should be operated as close as possible to 100 percent full load. The degree of loading depends upon the metal in the workpiece, the coupling to the work, and the number of pieces in the coil.

Any heater has a limit to the amount of metal it will heat in a given time for a given job. If the heater will not do the work, using a properly designed coil, it is too small. On the other hand, if the work is heated properly and the machine load is far from full load, more pieces can be heated at one time.

The rate of heating of the piece depends upon the piece and the operation to be performed. To case harden a piece of steel, surface heat must be generated fast enough so that the heat cannot penetrate deeply into the metal before quenching. On the other hand, in brazing applications a slower heating rate (and usually a lower temperature) is required because the flowing of the brazing agent must be complete. Other induction heating applications such as soft soldering, annealing, and melting require correspondingly different heat conditions.

Now, of course, the number of pieces which can be heated simultaneously depends upon the rate of heating of each piece and the percentage of the full load one piece may take. Thus the number of pieces should be such that full load is drawn and each piece is heated at the correct rate.

Let us examine a basic procedure which can be used on typical induction heating jobs.

Heat treating

The problem is to case harden to .060-inch depth a one-inch length of a one-inch diameter SAE 1040 steel rod.

First of all, the generator frequency must be high enough to keep the induced heat near the surface of the work, and the machine must have sufficient power output to keep the surface heat from penetrating into the core farther than the required .060-inch depth with resultant core embrittlement.

SIMPLE COIL DESIGN and work handling setup such as this provide a surprisingly high production rate. The lubricator subassemblies are brazed while passing through a long, narrow single-turn coil.

The coupling required to produce full load of the machine is different for each type of machine on the market. Some units are designed to allow the coils to couple to the work by varying amounts. Other units require extremely close coupling between the work and the coil, allowing less leeway in coil design.

Coil principles

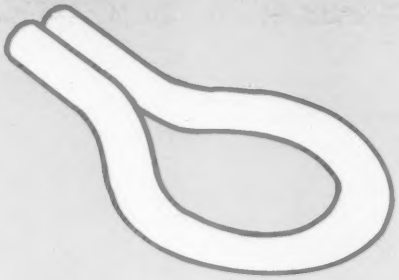
The ideal coil is one which fully loads the unit (although anything over 85 percent loading is usually considered as satisfactory) without making the work handling problem too complex. A clearance of 1/16 to 3/32 of an inch between the workpiece and the coil is the minimum value usually used. Anything closer than this means that work handling equipment must be designed to very close tolerances. While this may be possible, it is not so easy, especially at high production rates.

The work coil for hardening the bar in the problem might consist of one turn or several turns. The heating could be done in one shot or progressively by moving the bar through the coil. If progressive feed is chosen, a single turn of small diameter tubing can be used for the trial coil.

When a production size induction heater is fully loaded, a very heavy current is flowing in the work coil. From a practical standpoint, it is almost impossible to design an efficient coil for such heaters that does not require water cooling. Thus, any coil design must provide a path for cold water adjacent to or part of the coil itself.

Build sample coil first

With these facts in mind, a sample coil can be made up of copper tubing, since it is usually the simplest form of coil and provides both electrical and water connections at one



SAMPLE COIL of the simplest type in which water cooling and electrical connections can be made with flare nuts. Test coil should be made as accurate as possible. **(FIGURE 1)**

pair of terminals. A clearance of 1/16 of an inch around the rod can be used for the trial. Tubing having a 3/8-inch diameter and wound on a 1 1/8-inch form would provide a good start (Figure 1). Leads to the coil should be kept as short and as close together as practical (without, of course, the danger of touching). The trial coil should be made as accurate as possible so that results will be indicative of what to expect in the final coil.

With the coil connected and water turned on, the sample can be placed in the coil and the power turned on. If the unit is overloaded, as indicated on the load ammeter, the clearance between coil and workpiece must be increased until the machine is operating within its rating.

On the other hand, if the machine is loaded at below 85 percent full load, efficiency is low and the coil should be investigated for possible loss.

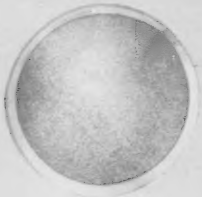
If no losses are found, the coupling may be increased but in so doing the work handling problems will be more difficult. There is also the possibility that, in the case of a vacuum tube oscillator type of heater, the coupling was already too close, blocking the oscillator. In this case a high degree of loading will be indicated on the plate meter with no apparent heating in the work piece. This may be corrected by decreasing the coupling.

Check sample work

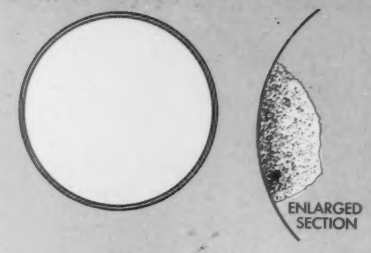
Provision for quenching should be made at least temporarily so that the hardness of the sample can be checked. Without provision for checking any coil designer is still working in the dark on heat treating jobs. The sample should be cut both axially and radially to check the heat pattern. The case should be a well defined area of the proper depth without a "burned" area near either edge.

The profile of the heated sections should be checked. Results will fall into one of the three following classes:

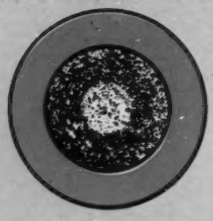
1. *The case may indicate a well designed coil* (Figure 2) that with slight modification will do a good job. The coil may now be redesigned to meet the specific production job using the coil construction techniques outlined later in this article.
2. *The sample may have burned surfaces and too thin a case* (Figure 3). The reason for this is too much power is forced into the piece in too short a time. The time cycle should be lengthened. Three possible methods present themselves:
   a. The work coil may be enlarged, thus decreasing the power into the piece. The result would also be a decreased load on the unit and thus a less efficient operation.



MICROPHOTOGRAPH of an etched specimen showing case on one-inch bar stock. **(FIGURE 2)**



ROUGH AND BURNED edges are obtained when heat is applied too rapidly. Enlarged section shows an unsatisfactory case. **(FIGURE 3)**



CASE HARDENING is too deep, a result of heating too slowly. In some specimens, the case may not be as well defined. **(FIG. 4)**

b. Reactance in the form of a variable series inductance may be added with the same results outlined above.

c. One good solution is to make a multiple coil in which two or more pieces can be heated at the same time. The result will allow operation of a fully loaded machine for a longer time cycle and, therefore, a deeper case.

d. If the area to be hardened is larger than that treated with the sample coil, as it is in this example, the final coil can be modified with the same results as adding more pieces. For instance, two or three turns of square copper tubing or a single heavy turn of one inch wide copper bus might be used for a final coil.

3. *The hardened zone on the sample may be too deep or all the way through* (Figure 4). The cause is too long a heating cycle. If no case is obtained when the cycle is shortened, the machine does not have enough power to do the job with the sample coil. The next step would be to reduce the projected area of coil on the surface of the rod by using a smaller tubing for the sample coil. If this fails the heater is too small.

While these are the steps suggested for a relatively simple heat treating application, the same procedure can be followed for even the most complicated coils. Experience will bring with it many short cuts to the process listed here. Later in this article are listed many of the coil variations that can be used.

Designing coil for brazing

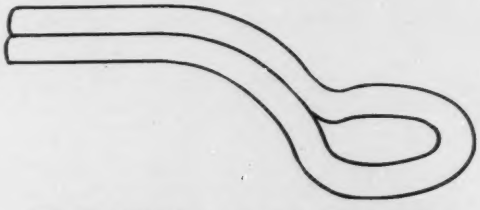
Brazing and soft soldering represent quite a different problem in coil design. Here the goal is to get the heat into the work piece slowly so that the heat will penetrate, bringing the brazing zone or zones up to the temperature needed to procure a good bond.

Let us examine the steps in designing a coil for brazing the joint in the assembly shown in Figure 5. It is here that the thin sections must not be heated too fast compared to the thick sections having greater heat capacity, or burning will result. Since the pipe has the thinnest wall, power must be concentrated in the shell and apron to heat the joint more uniformly.

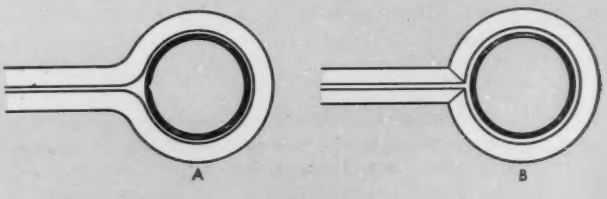
We have here a choice of heating this work piece from the inside or the outside. Since an inside coil would require longer leads with lower efficiency and probably more difficulty in work handling, an outside coil was chosen.

The next step is to make up a test coil following the same procedure as in the previous example, remembering that we

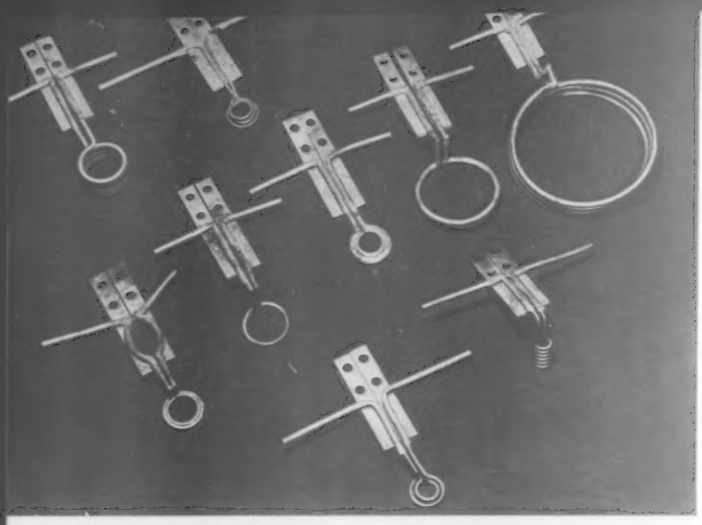
UNIFORM BONDING at the brazed joint of the oil filter shown above was achieved through brazing with induction heat. Heat was applied slowly so that it could penetrate work piece evenly. **(FIGURE 5)**



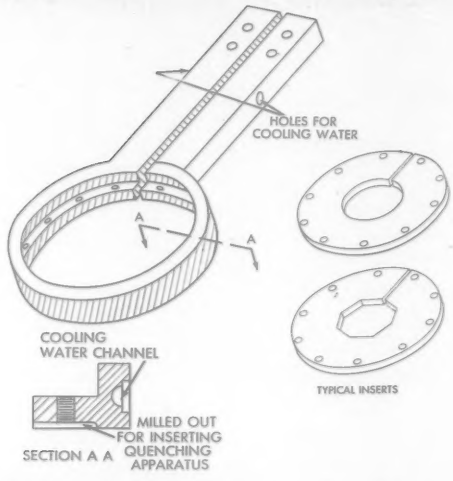
SIMPLEST FORM of coil chosen for brazing filter shown in Figure 5 consists of two coils wound with 3/16-inch diameter tubing on a 3/4-inch form. Leads are bent to provide clearange. **(FIGURE 6)**



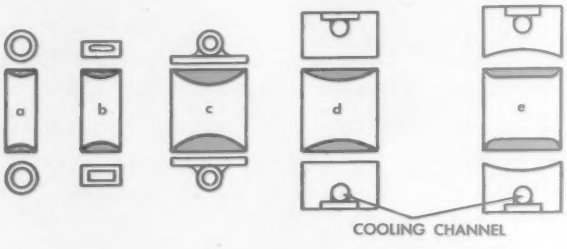
BENT TUBING makes it almost impossible to avoid variation in case thickness (a), unless work is rotated while heating. In (b), mitered joints provide a more uniform case. **(FIGURE 7)**



SAMPLES OF THE MANY coils that can be matched to the same induction heater. All of these experimental coils use copper bus for support and electrical connections. Final water cooling connections are not shown.



REMOVABLE MOUNT COILS, such as the one shown above, are simple and easy to make. Almost any type of insert can be cut from copper bus and bolted in place. A quench block can be added, if desired. **(FIGURE 9)**



HEAT PATTERNS obtained with five common coil cross-sections are shown above. Using these as a guide, almost any desired heat pattern can be achieved without too much difficulty. **(FIGURE 8)**

wish to heat the piece slowly and, at the same time, strive to utilize the full output of the heater by loading into as many pieces as possible at one time.

The resulting coil will not require careful machining, so a ¾-inch I.D. coil made out of 3/16-inch copper tubing might be a good choice. The work piece can be shifted up and down to get the proper heat proportions in the pipe and in the shell and apron.

Results can then be judged as in the previous example, sawing through sections of the braze to check its effectiveness, and modifying the final coil to suit the results.

Actual brazing coil design

The coil design chosen for this job on a production basis consisted of two coils in series with inductances in series with each coil as shown in Figure 6. The coils were wound with 3/16-inch diameter tubing on a ¾-inch form. On a 450-kc, 20-kw heater, the heating time was 30 seconds, brazing two shells simultaneously. A ring made up of brazing alloy was inserted between the shell and the apron prior to heating.

With the above examples in coil building procedure, we can proceed to the best known variations in coil design that have evolved in the past several years.

Single turn coils are versatile

Coils comprising a single turn are very versatile and can be readily modified to meet the demands of a surprisingly large number of the many heating problems encountered in actual practice. Simplest in design is one made of round copper tubing.

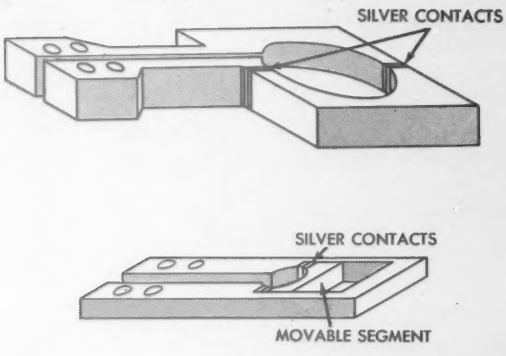
However, such a coil produces a heat pattern like that shown in Figure 7a. By completing the coil circle and mitering and brazing the leads, as in Figure 7b, a much improved and uniform pattern is obtained.

Figure 8a shows the type of heat pattern obtained with such a coil. If the coil is combined with quenching apparatus adjacent to it and the work (a rod or shaft) progressed through the coil and quench, the result will be a hardened case, assuming that the material is of a hardenable nature.

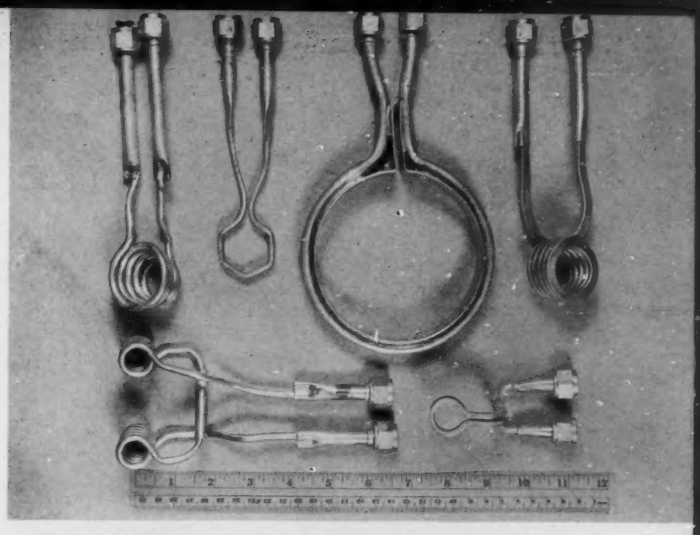
The heat pattern can be extended by using rectangular tubing, shown in Figure 8b. A further extension of the heat pattern can be obtained by brazing a copper band of the required width on the inside of the copper tubing (see Figure 8c). This band need not be any heavier than 1/16 of an inch, but it must be brazed to the copper tube, not soft soldered, since enough heat may be developed to melt the soft solder.

Single turn coils thus far discussed are easy to make, but have the disadvantage that they can be easily deformed. Many production set-ups are such that it would be desirable to have a more rigid and durable coil. While it is possible to reinforce and support the above coils, a more satisfactory method is to machine the coil out of copper stock, as in Figure 8d. A cooling channel is usually milled around the coil and a cover brazed over the channel. In making such a coil, it is well to bear in mind that the currents in the coil are confined to the surfaces adjacent to the inside diameter and to adjacent surfaces of the buses. In order to be effective the cooling channel should be as close to these current carrying areas as is possible.

Referring to Figure 8d, it is seen that even with machined coils the heating pattern is not necessarily uniform, especially if the length of the heat pattern is appreciable as compared to the diameter. Since the heat developed is a function of the flux linking the work, the heat can be decreased or increased more or less at will by changing the clearance between the



HINGED OR SEMI-OPEN coils can be designed for applications where the workpiece is such that it cannot be moved into the coil freely. Silver contact surfaces are essential for this type of coil. **(FIGURE 10)**



WHERE COIL CURRENT is not high, fittings similar to the ones on these experimental coils can be used. Samples of the many less commonly used coil designs shown above utilize round and rectangular tubing.

work and the coil. By increasing the clearance (Figure 8e), the heat pattern can be made uniform over the length of the heated zone.

It sometimes happens that a number of different shafts, pins, or rods call for the same type of treatment. A single coil can be made like that in Figure 9, having removable inserts with different inserts for each size or shape of work piece. From a production point of view, such a coil is time saving, rugged, and durable. It can be designed so that a quench block is easily attached if desired. The problems involved in building this type of coil are such as can be readily handled by any toolroom or machine shop.

Occasions arise when it is necessary to either open or enlarge the coil in order to get the work in or out. Figures 10a and 10b show two such designs. The first is a split coil which is nothing more than a machined coil made in two parts having silver contact surfaces. It is necessary to firmly clamp the coil during the heating cycle. This can be accomplished by means of levers, solenoids, hydraulic or air cylinders.

Figure 10b shows a machined coil with a movable insert which allows the piece to be removed from the coil without actually opening it. Considerable ingenuity can be exercised in the construction of these types of single turn coils. It is well to point out, however, that the manner in which these coils work out in practice will depend somewhat upon the characteristics of the machine to which they are attached.

Multi-turn coils for internal heating

Coils having more than one turn comprise the other general category of induction heating work coils. These coils are made from round or rectangular tubing. If it is desired to obtain high power densities it is necessary that the coil be wound with the maximum number of turns for a given length. Several factors, however, limit the extent to which this can be done.

First of all, the tubing cross-sectional area must be sufficient to carry the currents involved. Secondly, the water flow through the coil must be sufficient to keep the coil cool. As a general rule ⅛-inch tubing is the smallest that can be employed on heaters rated ten kilowatts or more — with 3/16-inch tubing preferred. And third, the voltages developed across multi-turn coils are higher than those on single

MULTI-TURN COILS must be insulated from each other. A recently developed enamel for copper provides thin but sturdy insulation which is unaffected by water and acids. **(FIGURE 11)**

turn coils — so much so that, if the coils are large, it may be necessary to insulate the turns from each other. This can be done by baking an enamel coating on the coil, painting the coil with an insulating compound such as glyptal, or wrapping the coil with glass or cotton tape and then impregnating with an insulating compound. A simple coil using a newly developed porcelain enamel for copper is shown in Figure 11.

Multi-turn coils of appreciable length can develop a wide variety of heat patterns. Figure 12a shows a typical pattern obtained with such a coil. Notice that this pattern is identical to that obtained with the wide single turn coil. The pattern can be corrected, as in the machined coils, by increasing the clearance between the work and the inner turns of the coil (Figure 12b). To wind a barrel shaped coil, however, requires the use of a formed mandrel and at best is a difficult job. An easier method is to vary the spacing between turns in such a manner that it is greater in those areas that would normally overheat (center) than at the ends as in Figure 12c. There is the possibility that the spacing between turns might be too great in which case the heat pattern will be striated.

Multi-turn coils are generally most satisfactory for heating internal surfaces of tubes, cylinders, and bores. All previous remarks relative to multi-turn coils apply to the so-called internal coils, except, of course, the heat patterns shown in Figure 12 will be reversed and will be on an internal surface.

Some difficulty may be encountered in bringing out both leads to the coil from one end, especially if the diameter of the coil is small. The winding of an internal coil can be accomplished by using a hollow form of correct diameter as in Figure 13. Sufficient length of copper tubing is fed through the tube and the coil wound on the form in such a direction as to double back over the lead. A notch cut out of the tube form will assist in making a neat bend in the lead to start the first turn. After the desired number of turns the coil is slipped off the form and end turn bent so as to bring out the second lead close to and parallel with the first. The leads are cut and bent as required for the particular case. Be sure that the tubing is thoroughly annealed before winding, otherwise the coil will spring out when finished, increasing the diameter.

Compared with coils which surround the work, these internal coils are relatively inefficient, and difficulty may be experienced in loading the heater to full capacity. This difficulty can be minimized by using rectangular tubing wound on edge and thus obtaining the maximum number of turns for the given coil length. Clearance between work and coil should be as close as is practicable.

Flat coils are best for flat surfaces

It may be necessary to heat flat or plain surfaces — pancake or flat coils like that shown in Figure 14 are used for such applications. This type of coil is made by winding the copper tubing laterally, usually with some material such as soft brass or copper strip to provide proper spacing between turns during winding. Such coils can be made in any shape — circular, rectangular, square, etc. Unless this type of coil is braced with some insulating board, it may be very flimsy and can be easily deformed by the slightest jar. Figure 14 shows such a coal brazed to ¼ x 1 inch copper buses, increasing both the rigidity and the efficiency of the setup.

Of the multi-turn coils this is by far the least efficient and very close coupling is desired, although it is usually difficult to achieve on a production setup because of the danger of bumping or bending. It is not necessary to wind the coil with concentric turns. Flat grids of other design are possible, although efficiency is sacrificed.

Combination coils require cut and try

As was discussed, in those cases where the objects to be heated are small or where high power densities are not required, better production rates and higher machine utilization factor can be obtained by heating a number of pieces simultaneously. The work coil in such a case can be a number of identical multi-turn coils in series, as shown in Figure 15. In order to obtain a rugged structure with the dimensional stability that is required when using fixtures for mounting and holding the parts to be heated, the individual coils can be wound separately and mounted on and connected by buses. In this case, care must be exercised to keep water or brazing flux used in the production process and alloy away from the buses lest short circuits develop.

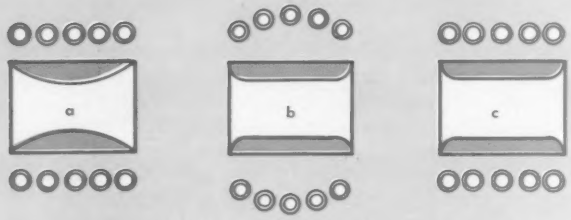
When the heat is to be confined to relatively small areas of the piece, a coil machined from sheet or bus, ¼ inch or more in thickness, will probably be found to be most practicable. Such a coil is shown in Figure 16. Cooling must be provided for such coils. As before, this can be accomplished by means of a milled water channel or tubing brazed (not soldered) on the periphery of the coil and buses.

Coils can also be connected in parallel or series-parallel combinations. A great deal of experimentation is often required to obtain the desired heat patterns and heating rates in the various positions, since the heating in each position is dependent on conditions in the other coils. In spite of the difficulties that might be encountered in working out the designs, these types of coil hold sufficient promise in results to be achieved to warrant consideration. The coil in Figure 17 was designed and built to braze two thin tubes and one heavy coupling to a base in one operation. The coils for the thin tubes are in series and have long leads while the coil for the heavy coupling has short leads and connected in parallel with the two series connected coils. Fine adjustment of heating rates can be accomplished by altering the spacing between coil leads, particularly on the coil for the heavy coupling. Spreading the leads of this coil will slow up the heating rate of the heavy sections and simultaneously increase the rate for the thin tubes. The converse is also true.

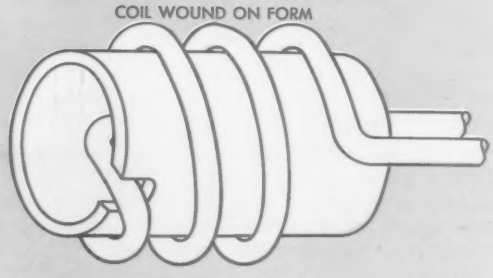
Handling irregular surfaces

Any sharp edges or irregularities which may be in the field will tend to overheat or even burn. The simplest types such as the ends of stock and regular sharp edges may be handled by controlling the coupling, with the coil coupling less to the sharp edges than the regular sections.

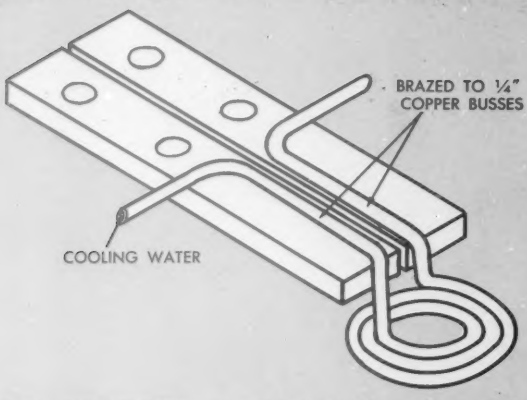
Where a surface is interrupted by a sharp edge such as a keyway, hole, or slot, the heat may be evened out by forcing a piece of copper in the work piece previous to inserting it in the coil, thus short circuiting the area.



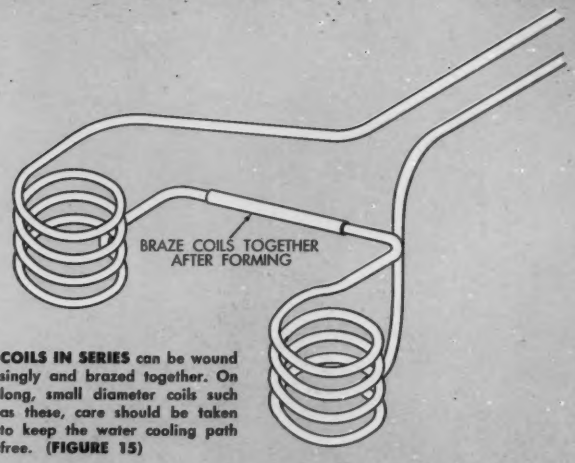
HEAT PATTERNS provided by multiple-turn coils are much like those of the wide, single-turn coil cross-sections shown in Figure 8. Note that irregular spacing in c provides same pattern as coil b. **(FIGURE 12)**



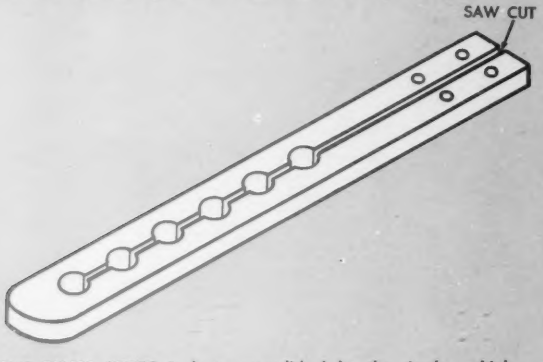
INTERNAL HEATING COILS can be wound on a form similar to the pipe used in the above illustration. Tubing must be thoroughly annealed before winding to retain its shape. **(FIGURE 13)**



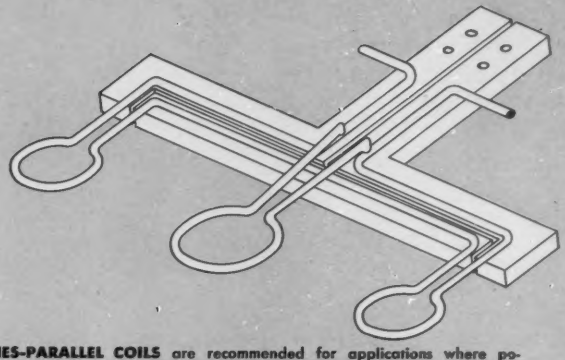
SPIRAL PANCAKE COILS are preferred for flat surfaces. For top efficiency, coils should be wound tightly and uniformly spaced. These coils normally have cool spots where the leads are beaten away. **(FIG. 14)**



COILS IN SERIES can be wound singly and brazed together. On long, small diameter coils such as these, care should be taken to keep the water cooling path free. **(FIGURE 15)**



HEATING SMALL AREAS is best accomplished by the simple multiple position coils shown above. Coil is made from copper bus, drilled and sawed. For cooling, copper tubing is brazed to outer edge of the coil. **(FIGURE 16)**



SERIES-PARALLEL COILS are recommended for applications where positioning is difficult, and where production with a minimum of help are major considerations. Space between coils determines heat rate. **(FIG. 17)**

Start with right tools

Coil building is still a skill, and both the right tools and men who know how to use them are important. Patience, creative ability, and practice will develop a man skilled and quick in making coils.

The usual hand tools available in every plant cover the requirements pretty well. Flaring and cutting tools for tubing are essential. A bench vise with copper jaw inserts, compressed air facilities, oxyacetylene torch with a wide range of tip sizes, and a water quenching tank should be provided. For making the final coils from bus copper, a band saw, jig saw, drill press, lathe, milling machine, and shaper will be helpful.

Annealed copper tubing should be used in all coil construction. If the tubing is not thoroughly annealed when purchased, it can be annealed by heating the copper to 1,000 degrees F and plunging immediately into cold water. It may even be advisable to reanneal complex coils in the middle of the winding process if the copper becomes work hardened. Care must be taken to prevent the tubing from collapsing, especially where sharp bends are to be made. Where possible, brazed mitered joints are preferred. Where this is not practical, small radius turns can be made, using the filled tube method.

In this method the inner surface of the tubing is coated with a light lubricating oil, after which it is placed in a pan of warm water and brought to a temperature of 180 degrees F or higher. The tube is then filled with molten low temperature alloy, such as Wood's metal or Cerro-Bend. Quenching the filled tube in cold water will solidify the alloy. The tubing can then be bent into any configuration without danger of collapsing. Before using the coil, be sure the alloy has been melted out by placing the coil in hot water. Rectangular tubing should invariably be formed using the filled tube method.

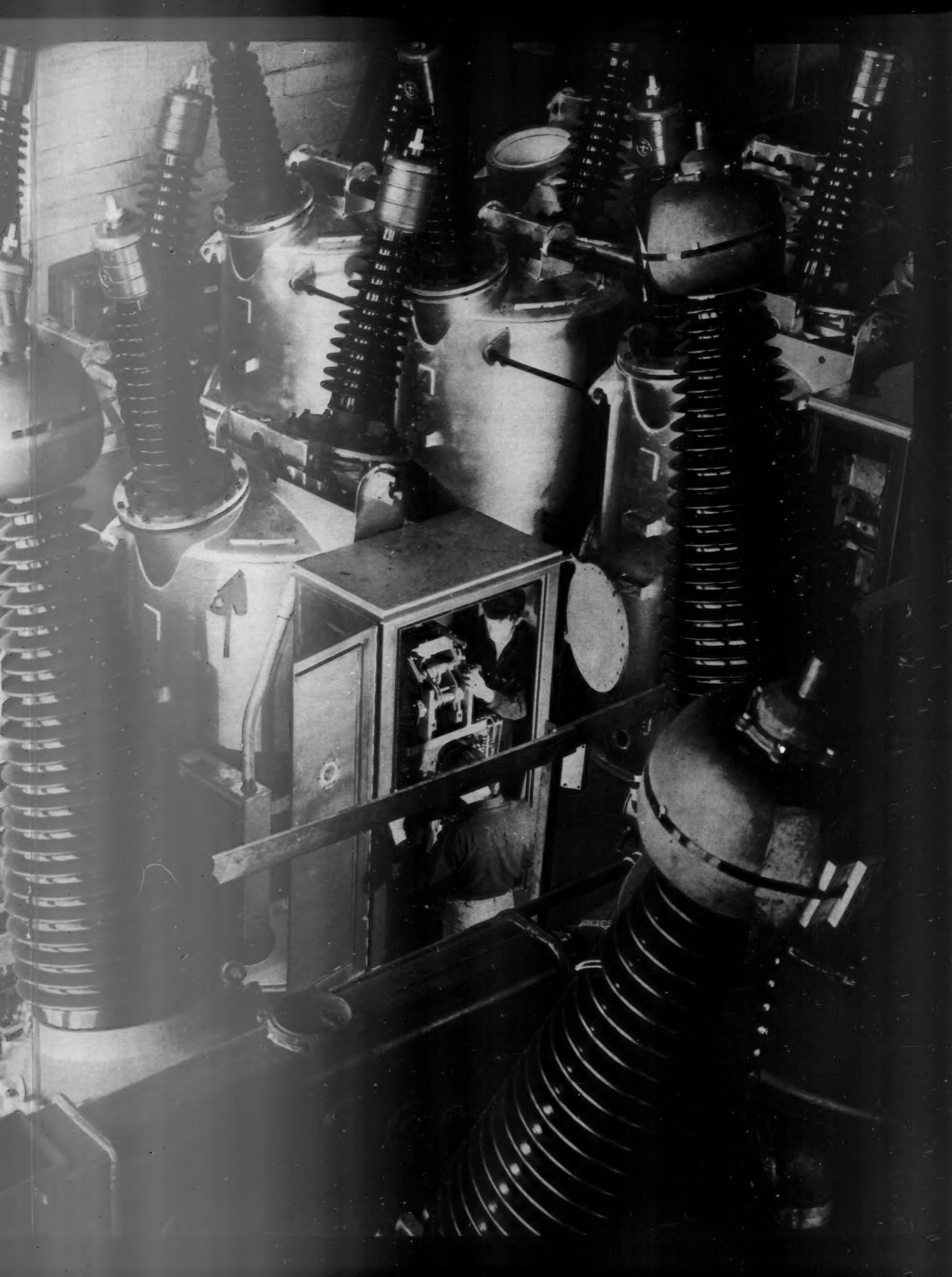
Use high temperature solder

All joints should be brazed with high temperature material such as the silver solders which have high strength and good electrical properties. Soft solder is usually unsatisfactory because its melting point and mechanical strength are low.

The problem of brazing two miter joints which are very close to each other often arises in practice. To keep the first braze from remelting while the second joint is being done, several possibilities are open. The two joints can be done at the same time. Or the whole assembly can be rigidly clamped during brazing. Another method which is used at times is to leave part of the tubing stock uncut, filing a deep notch almost all the way through the tubing for the inside edges of the miter. The thin wall section will support the joint during brazing.

Avoid using excessive flux or brazing alloy. Have the joint surfaces clean, smooth, and very tight fitting. Watch the coil closely while working and avoid slipshod preparation. After brazing and filing, the coil can be pickled in an acid bath, and blown out and it will be ready to test.

FIFTEEN MILLION KVA interrupting capacity is represented by the six pneumatically operated, floor mounted, outdoor oil circuit breakers being prepared for testing in one corner of the breaker production floor at the Allis-Chalmers Boston Works. Control mechanism of the first 115-kv, 2,500,000-kva interrupting capacity breaker on the left is being tested for opening, closing and reclosing speeds and times.



Fundamentals of A-C Circuit Interruption

PART ONE OF FIVE PARTS[1]

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Circuit interruption is an applied science, dealing with arcs and arc extinction.

TODAY, more than ever before, electric power is a mighty force in our industrial progress, in our national defense, and in our own personal everyday good living. The capacities of electric power systems and their interconnections have pyramided to values hardly dreamed of a few years ago. Individual power plant capacities of as much as a million kva may shortly be a reality.

It is an axiom in electric power operation that power that is connected — whether intentionally, in the form of load, or accidentally due to overload or short circuit — whether it is a tenth kva load or a ten million kva short circuit — must be interrupted. Without circuit interrupting devices, the operation of even the smallest electric power system would be completely impractical.

For many years the achievement of circuit interruption carried with it something of an air of mystery, and it was traditionally known as an art — not a science. Much has been written on specific phases and problems of circuit interruption during its progress from an art to what is now predominantly an applied science, but few attempts have been made to collect and condense the whole fundamental story of circuit interruption.

Circuit interrupting devices

The terms used for designating different circuit interrupting devices are, in general, based upon their operating characteristics. Circuit interrupting device is a generic term covering any device for interrupting an electric circuit. Making, breaking, and changing connections in a circuit in which the flow of current does not exceed load proportions is called switching. Hence the circuit interrupting device designed for this service and limited to it is called a switch. The circuit interrupting device intended to interrupt or break abnormal or fault current, as well as to perform the functions of a switch, is called a circuit breaker. The terms switch and circuit breaker both refer to circuit interrupting devices having a pair of cooperating separable contact members adapted to form a circuit-interrupting gap upon their separation.

A circuit interrupting device for interrupting overloads having a circuit opening fusible member directly heated and destroyed by the passage of the overcurrent through it, is called a fuse.

Circuit interrupting devices intended for purposes of protection, such as automatic switches, circuit breakers, and fuses, are referred to as protective devices.

Principles and problem

The pair of cooperating separable contact members with which a switch or circuit breaker is provided is adapted to be opened and closed by mechanical means. Normally, the contact members are held in engagement under pressure and the electric current flows from one to the other through the point or points of contact engagement. Interruption of the circuit is initiated by separating the contact members.

When a pair of cooperating contact members is separated, a progressively widening gap is formed between them. That gap constitutes a gaseous conductor of electricity as long as it remains in the particular condition which it acquires during the time of initial contact separation. Because of that condition, the current leaves its metallic path at the surface of one of the contact members, passes through the gas filled gap space, and enters the surface of the other contact member. The current-conducting gaseous section of the circuit inserted into it by separation of the contact members is known as an electric arc. It is this section, where the current leaves its safe metallic path to form an arc in gaseous space, that the circuit is vulnerable, since it is here that the conductivity of the current path can be impaired to a point where current flow must cease.

Interruption of an electric circuit thus comprises two consecutive steps: the first consists in inserting a section of gaseous conductor into the all-metallic current path previously existing, and the second consists in depriving this gaseous section of its current conducting ability. The fundamental principle underlying this two-step process is the rapid conversion of a predetermined section of the circuit from a conductor of electricity into an insulator.

Circuit interruption deals with arcs and its basic problem is arc extinction.

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[1] This series was originally intended for publication some time ago. The first installment appeared in the December, 1944 ELECTRICAL REVIEW. Because of the pressure of work at the time, Dr. Salzer was unable to continue the series. All of the material has now been brought up to date and will be published in consecutive issues of the REVIEW.

Structure of matter

The nature of an arc can best be understood by first considering the structure of matter. It is now established that all matter is made up primarily of three extremely minute fundamental particles — the neutron, the proton, and the electron — each of which is much smaller than the molecule or the atom. As its name implies, a neutron has no electric charge. Each proton carries a positive and each electron a negative electric charge 1.6 x 10^{-19} coulombs in size. While the electric charges of the proton and electron are equal, though opposite in polarity, the mass of a proton is about 1,800 times that of an electron.

Every atom consists of a small heavy nucleus approximately 10^{-12} centimeters in diameter, made up of protons and of neutrons. The total number of protons and neutrons is equal to the atomic weight. The number of protons in the nucleus is called the atomic number and it determines the chemical properties of the atom. Changing the number of protons results in a different chemical element. The nucleus of an atom is surrounded by a substantially empty region having a diameter of 10^{-8} centimeters, in which a number of electrons move in satellite fashion along remote orbits around the nucleus. The number of electrons circulating around the nucleus is normally equal to the number of protons in the nucleus; hence the charges within the atom are normally balanced and its net charge is zero. Typical atom structures are shown in Figure 1.

The outer electrons which move in satellite fashion about the nucleus can be removed from the atom with relative ease and can be caused to travel freely through space. Such free electrons constitute the major portion of an arc current.

Ionization

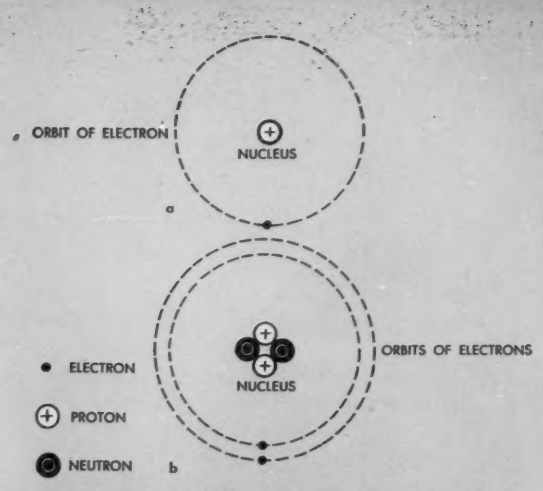
The removal of one or more of the satellite electrons from an atom or molecule is called ionization. By ionization, the atoms and molecules of an electrically neutral gas are broken up into free negatively charged electrons and positively charged ions. A positive ion can thus be defined as the remainder of an atom or molecule after one or more electrons have been removed from it, thus upsetting the normal balance of electric charges, leaving it with an effective positive charge. It is by the process of ionization that the gap formed upon separation of a pair of cooperating contact members is rendered conductive.

Ionization is not to be confounded with atomic or nuclear fission. Ionization is the process of releasing one or more electrons from their remote orbits around the nucleus of an atom. Nuclear fission is the process of splitting the nucleus itself, with the attendant release of enormous quantities of energy.

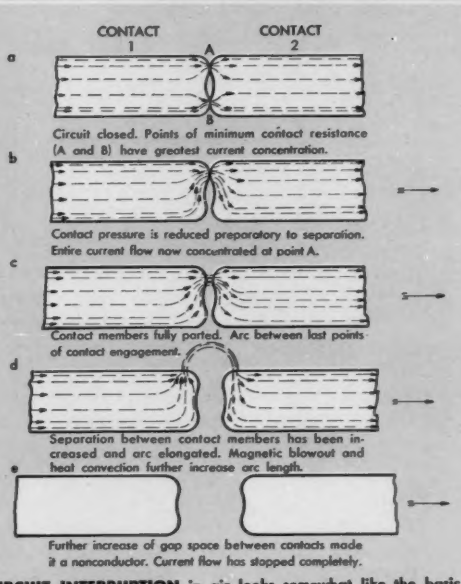
The ionization of an atom or molecule requires the expenditure of a definite amount of energy and may be effected in various ways.

In a gas where the velocity of random motion of the neutral atoms or molecules is high, as when the gas is hot, ionization may be caused by the impact of one upon another of two neutral atoms or molecules. This process is called thermal ionization.

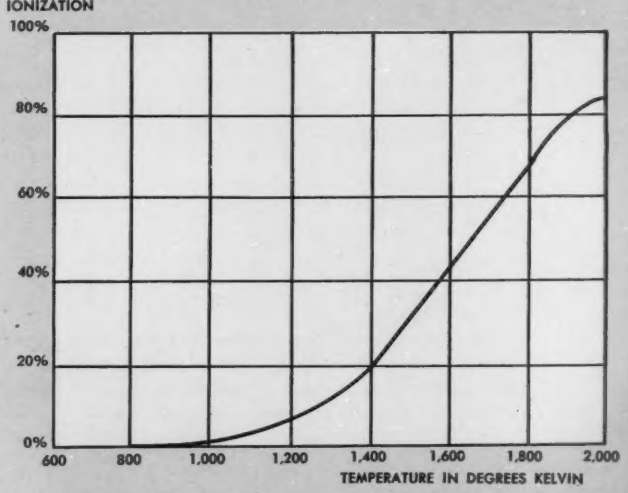
A neutral atom or molecule may also be ionized by collision with a free electron or an ion, either of which has been sufficiently accelerated by the action of an electric field to



ATOMIC STRUCTURES identify chemical elements according to the number of protons found in the nucleus. A hydrogen atom (a) consists of a single proton and electron. An atom of helium (b) has two protons, two electrons and two neutrons. **(FIGURE 1)**


CONTACT 1
CONTACT 2
A
B
a
Circuit closed. Points of minimum contact resistance (A and B) have greatest current concentration.
b
Contact pressure is reduced preparatory to separation. Entire current flow now concentrated at point A.
c
Contact members fully parted. Arc between last points of contact engagement.
d
Separation between contact members has been increased and arc elongated. Magnetic blowout and heat convection further increase arc length.
e
Further increase of gap space between contacts made it a nonconductor. Current flow has stopped completely.

CIRCUIT INTERRUPTION in air looks somewhat like the basic pattern above. Small arrowheads indicate the direction of current flow, while large arrows at the right show the direction of motion of the movable contact members. **(FIGURE 2)**



IONIZATION of typical metal vapor plotted against temperature in degrees Kelvin. The absolute temperature, or degrees Kelvin (°K) T, is related to the temperature in degrees Centigrade by the equation T=(t+273). **(FIGURE 3)**

acquire the amount of kinetic energy needed to knock off one or more electrons from the neutral atom or molecule. This is referred to as ionization by collision.

Emission from solids

Electrons and, in some instances, positive ions, may also be emitted from solids. In case of circuit interrupters the main solid sources of electrons are the contact members and, to some extent, insulating walls or barriers.

Electrons may be emitted by the surfaces of solids at high temperatures, principally from the surfaces of heated metals. This is called thermionic emission.

High field emission, in which electrons are apparently drawn out of small surface irregularities of cold metal due to an intense electric field, is another probable source of electrons.

Electron emission may also take place from surfaces as a result of bombardment of the surface by electrons or positive ions. When a high velocity electron or ion hits a surface, a secondary electron may be emitted from it.

Electrons emitted from solids may be responsible for a significant increase of the degree of ionization of the gap formed upon separation of a pair of cooperating contact members in a circuit interrupting device.

Arc initiation

An arc is a self-sustained discharge of electricity in a gaseous atmosphere, i.e. a discharge which itself produces the electrons and ions of which it consists. Arc discharges distinguish themselves from other forms of gas discharges by their much higher current intensities and current densities and lower voltage drops. Arc discharges are composed of an intensely luminous, extremely hot core, surrounded by an envelope of hot, though relatively lower temperature gases.

The contact members of a circuit breaker or switch are normally held closed under pressure. The resistance between them depends, among other factors, upon the amount of contact pressure. This contact resistance increases with decreasing contact pressure. At the instant of contact separation, as shown in the series of drawings in Figure 2, the contact pressure at the last point of contact engagement, constituted by minute surface irregularities on both contact members, is zero, and the contact resistance is correspondingly high. Since current flow and heating are concentrated in the minute areas of these surface irregularities, they are heated to very high temperatures.

These high spot temperatures of the contact members may cause substantial thermal emission of electrons from the hot spots of the negative contact member or cathode. The electrons so emitted are acted upon by the electric field that prevails in the gap formed between the separated contact members. These electrons may become sufficiently accelerated by the action of that field to ionize that gap by collisions with neutral gas atoms and molecules. An arc discharge is initiated when the voltage across the gap between the contact members and the degree of ionization of the gap are sufficiently high.

An arc current consists of an electron current (known as conduction current) flowing from the negative contact member or cathode to the positive contact member or anode, and of a positive ion current (known as convection current) flowing in the opposite direction. In an alternating current circuit, the direction of flow of these currents is reversed each half cycle of the current wave. Since the mass of an electron is much smaller than that of a positive ion, its speed under the action of the same electric field is much higher than that of a positive ion. Consequently the major portion of the arc current is due to the flow of electrons, and the portion of the arc current due to the flow of positive ions is very small or negligible by comparison. Thus it is the electron current which must be made the major target of attack in circuit interruption.

Deionization

Deionization is the process of restoring an ionized gas, consisting of electrons and positive ions, to its original electrically neutral state. Deionization is the reverse of ionization. It is by the process of deionization that the gap space between the separated contact members of a switch or circuit breaker is converted from a gaseous conductor of electricity into a gaseous insulator.

In the case of a stable arc — not encountered in normal circuit interruption — reignition continues to occur after every consecutive current zero. Circuit interruption is concerned with unstable arcs in which the rate of deionization exceeds the rate of ionization. Deionization of the arc path may progress from half cycle to half cycle of the current wave until, after a number of half cycles, complete arc extinction is achieved or, the rate of deionization of the arc path may be so high that complete arc extinction is achieved at or about the time of the first natural current zero following arc initiation. The rate at which the arc path is being deionized is a most important factor, and it is a general aim in the design of switches and circuit breakers to increase that rate as much as possible in order to accomplish rapid and efficient circuit interruption.

The most obvious way of deionizing the arc zone in a circuit interrupting device is by bodily removal of the ionized gas and simultaneous replacement of it by un-ionized gas. This can be effected by establishing a blast of un-ionized gas which sweeps away and replaces the gas that has been ionized by the arc.

Wherever ionization, or the degree of ion concentration, is not uniform, electric charges tend to flow from regions of relatively high to regions of relatively low ion concentration. This diffusion effect may result in relatively rapid deionization of the arc zone when the gas in that zone is in a state of agitation.

The temperature of a gas is proportional to the square of the average molecular velocity of its constituent atoms and molecules. Heating of a gas increases the average molecular velocity. At arc temperatures the average molecular velocities are so high as to cause atoms and molecules to break up, on colliding, into electrons and positive ions. Conversely, cooling a gas reduces the average molecular velocity and the kinetic energy of its constituents, resulting in a decrease of the rate of thermal ionization.

Deionization may also occur by neutralization of charges of opposite polarity. For instance, an electron and a positive ion may combine to form an electrically neutral atom or molecule. Or an electron may attach itself to a neutral atom or molecule, thus forming what is known as a negative ion which, in turn, may combine with a positive ion forming two neutral atoms or molecules.

These recombination processes may occur in space or in the presence of surfaces which favor recombination. Recombination may be greatly enhanced by violently mixing ionized and un-ionized gas as occurs in a turbulent gas flow. For this reason, turbulence, or the formation of eddies in a flow of gas, is considered to be a particularly effective deionizing means.

Effect of metal vapors

While in modern switches and circuit breakers the amount of contact metal vaporized by the heat of the arc is greatly minimized, metal vapors are still an important factor in circuit interruption. Hot metal vapors are good conductors of electricity, and thus tend to increase the current flow across the gap formed upon separation of a pair of cooperating contact members.

Conversion of that arc gap from its conductive to a non-conductive state involves bodily removal of metal vapors from the gap zone as well as reduction of the conductivity of metal vapors by cooling.

If a high temperature is not maintained at the gap zone, it rapidly loses its conductivity and the arc cannot persist. Figure 3 shows the effect of temperature on the degree of ionization of metal vapors. It is apparent from this typical curve that cooling converts a body of hot metal vapors from a relatively good conductor into a relatively poor conductor of electricity. Here a reduction of the metal vapor temperature from 1,700 to 1,100 degrees C results in a reduction of about 64 percent in the degree of ionization of the vapor. Hence, cooling of the arc zone is another aid to arc extinction and circuit interruption.

Effect of heat-transfer and gas pressure

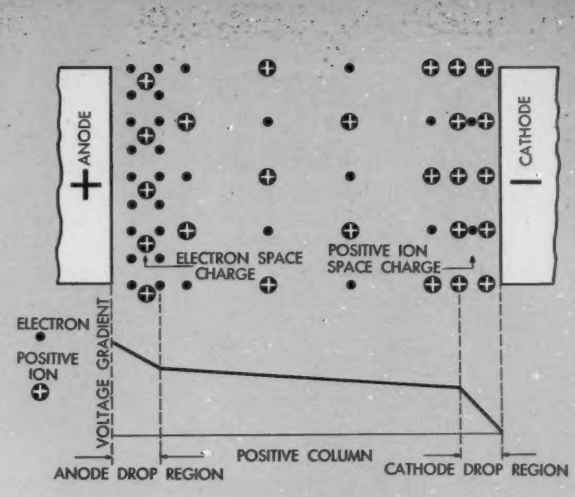
Other factors tending to accelerate the conversion of the arc zone from a good conductor into a poor conductor are the ability of the medium in which the arc is drawn to transfer heat by conduction and convection, as well as the pressure that prevails in the medium.

In oil circuit breakers the heat of the arc dissociates the oil, resulting in the formation of hydrogen. The favorable heat-transfer properties of the hydrogen thus formed account, in part, for the relatively rapid deionization of the arc zone in oil breakers.

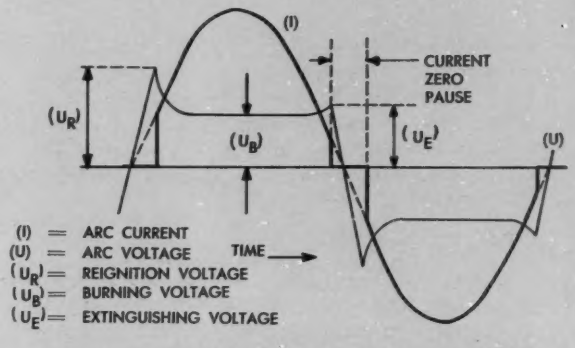
The dielectric strength of a gas, i.e. the maximum potential gradient it can withstand without breakdown, increases with gas pressure. This is a characteristic of considerable importance in a-c circuit interruption. Several types of circuit breakers employ arc enclosing structures in which elevated gas pressures prevail during the circuit interrupting process. These elevated pressures are in part responsible for the fact that higher voltages must be reached in such devices before re-establishment of an arc will occur after a zero of the current wave. If that elevated reignition voltage or gap breakdown voltage is not reached, complete interruption of the circuit has been achieved.

Characteristics of arc discharge

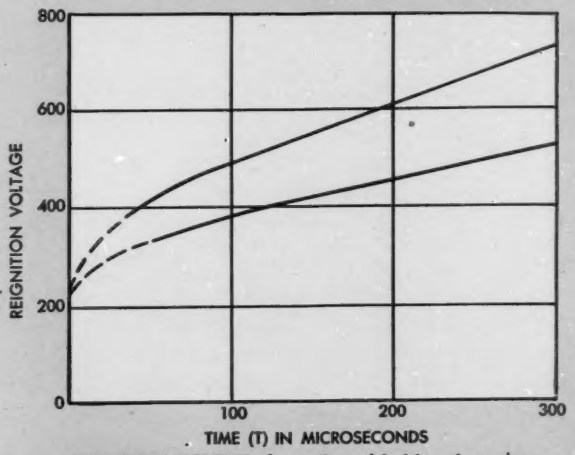
An alternating current arc, if not definitely extinguished at the end of a half cycle of the current wave, is re-established at the beginning of the consecutive half cycle. The arc residue, i.e. whatever amount of ionized gas still remains in the arc



SCHEMATIC DIAGRAM showing potential distribution along arc and the distribution of electric charges (electrons and positive ions) in the gap space. Widths of anode and cathode drop regions are greatly exaggerated for clarity. **(FIGURE 4)**



A-C ARC CURRENT i and voltage u across arc plotted versus time. For purposes of clarity, the case shown above has an extremely long zero pause. The dotted line portions of current i represent the normal current wave shape. **(FIGURE 5)**



REIGNITION VOLTAGE for various deionizing times shown above accounts for the reignition voltage peaks in Figure 5. Variations in contact material and size, radiation losses, etc., account for difference between two typical gaps. **(FIGURE 6)**

gap at the end of a half cycle of the current wave, may be displaced by convective or other motion. On account of such displacement of the arc residue, the arc may be re-established after current zero along a somewhat different arc path.

The temperature of an a-c arc varies with the current, and pulsations occur at twice the frequency of the arc current. The temperature peaks lag the current peaks, which is evidence of the time element involved in thermal phenomena. The temperature of the core of the arc varies widely, depending upon the circumstances under which the arc burns. It is of the order of several thousand degrees. The temperature of the arc envelope or arc surrounding gases is in the range of several hundred degrees.

Figure 4 shows, diagrammatically, the voltage distribution along an arc gap and the distribution of electric charges (electrons and positive ions) in the gap space. There are three distinct voltage drop regions: the anode and cathode drop regions, immediately adjacent the anode and cathode, where the voltage gradient is relatively high, and the intervening positive column region, where the voltage gradient is relatively low.

In the anode drop region there is an electron space charge, i.e. a larger amount of electrons than of positive ions, because the anode attracts electrons and repels positive ions. Similarly, in the cathode drop region, there is a positive ion space charge, i.e. a larger amount of positive ions than of electrons. In the positive column region, at any instant, the numbers of electrons and positive ions are approximately equal and their distribution is substantially uniform. But the electron current, on account of the far greater speed of electrons under the action of the electric field, exceeds by far the positive ion current.

In Figure 4, the widths of the anode and cathode drop regions have been greatly exaggerated for clarity. Actually the width or thickness of the cathode drop region does not exceed .00004 inch. The voltage drop in this thin cathode layer is from 5 to 20 volts, resulting in a voltage gradient of the order of hundreds of thousands of volts per inch. This high voltage gradient tends to greatly accelerate the positive ions in the cathode drop region, and the impact of these ions upon the cathode tends to raise its temperature and to increase its electron emission.

Time-voltage and time-current

Figure 5 shows, diagrammatically, the current (i) flowing in an a-c arc and the voltage (u) across the arc plotted versus time. The relatively constant voltage (u_b) is referred to as the arc burning voltage. At least temporary arc extinction occurs at the elevated voltage (u_e), or extinguishing voltage, just prior to every normal current zero. The still higher voltage (u_r), or reignition voltage, is that required to reignite the arc after current zero.

Upon reignition, the arc current rises, first rapidly and then more slowly, in accordance with its normal sinusoidal form, reaches its peak value and then decreases in intensity. As the arc current approaches zero, but prior to its natural zero, the effects of deionization and cooling of the arc gap become predominant, causing the arc voltage to rise above the average burning voltage to the value (u_e) and forcing the current to zero. The short period between arc extinction and arc reignition, during which the current is essentially zero, is known as the zero pause. Deionization of the gap space occurring during the zero pause is responsible for the fact that the reignition voltage (u_r) is higher than the extinguishing voltage (u_e) at the end of the preceding half cycle.

Reignition voltage vs. deionizing time

Since, in any arc discharge, at least partial deionization of the gap space takes place during the zero pause, the gap space must be reionized in order to re-establish the arc. This requires time and may require considerable voltage. Because of the time element involved in deionization and the time and voltage required for reionizing the gap space, arcs are said to have "inertia" characteristics.

In Figure 6 are two typical curves showing how the voltage required for re-establishing an arc increases with the time allowed for deionization of the gap space.

A-c and d-c circuit interruption

There is a basic distinction between the interruption of an a-c circuit and the interruption of a d-c circuit. In direct currents there are no current zeros and current zero pauses; hence, in order to interrupt a d-c circuit, the current must be forced to zero by progressively increasing the arc resistance until the voltage drop across the arc equals the circuit voltage. This may be achieved, for instance, by arc elongation or arc constriction.

In the a-c case, current zeros occur naturally, and it is only necessary to prevent reignition of the arc after a current zero. For this reason deionization of the arc gap close to the time of natural current zero is all important, while deionization of the arc gap close to the time of current peak usually does not significantly aid circuit interruption.

Crucial factors in a-c interruption

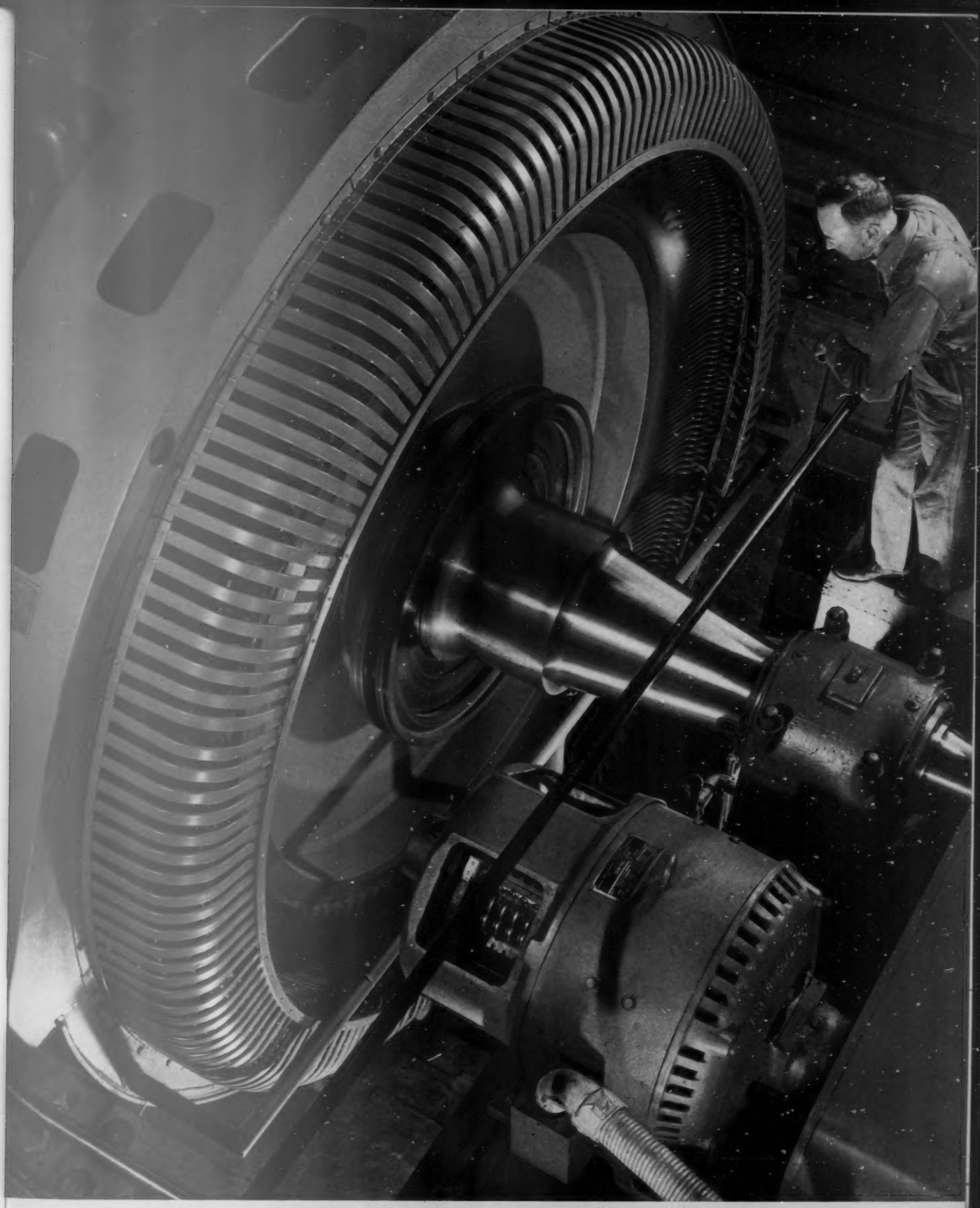
Whether or not final extinction of an a-c arc is achieved immediately after any particular current zero depends upon whether the value of the growing dielectric strength of the arc gap exceeds permanently the increasing voltage impressed upon the arc gap tending to re-establish the flow of current.

The dielectric strength of the arc gap at any particular instant is largely determined by the amount of ionization at the beginning of the zero pause and the subsequent rate of deionization.

The instantaneous values of the voltage tending to re-establish the flow of current across the arc gap depend upon the voltage impressed upon the gap at the beginning of the zero pause, its subsequent rate of rise, and the peak value to which it rises.

While there is a mutual interaction between the growth of the dielectric strength of the arc gap and the voltage which the circuit impresses upon it, the growth of the dielectric strength of the arc gap is primarily a characteristic of the circuit interrupter and the voltage impressed upon the arc gap primarily a characteristic of the circuit.

The next installment will deal with "The Relation between Circuit and Circuit Interrupter."



THIS 2,740-KW, diesel engine driven synchronous generator was recently installed in a Michigan utility plant. Rated 3,425 kva, 2,400/4,160 volts, 225 rpm, this unit is equipped with a 50-kw exciter driven by a multiple V-belt Texrope drive.

CHECK *that Ground*

Ground detector schemes guard power systems against serious damage.

R. LOEWE
Switchgear Section
Allis-Chalmers Mfg. Co.

ELECTRICAL distribution systems, like human beings, are subject to disabilities. In power systems, the most common of these is an accidental ground. As in the case of human ailments, a ground may not seem serious in the beginning but, if neglected, may prove disastrous.

A single ground occurring accidentally on an ungrounded electric system is, in itself, not a serious problem. However, a second ground would most probably result in a short circuit unless the two faults occur on the same polarity or phase. Therefore, it is necessary to learn of the first ground as soon as possible so that it may be found and removed before the second one occurs.

Ground detection methods vary

One of two things can be done. An alarm can be given by visual indication with lamps or meters, or both an alarm and indication may be had. The lamps or meters for indication will give the phase or polarity in trouble, whereas a scheme that is purely alarm will not.

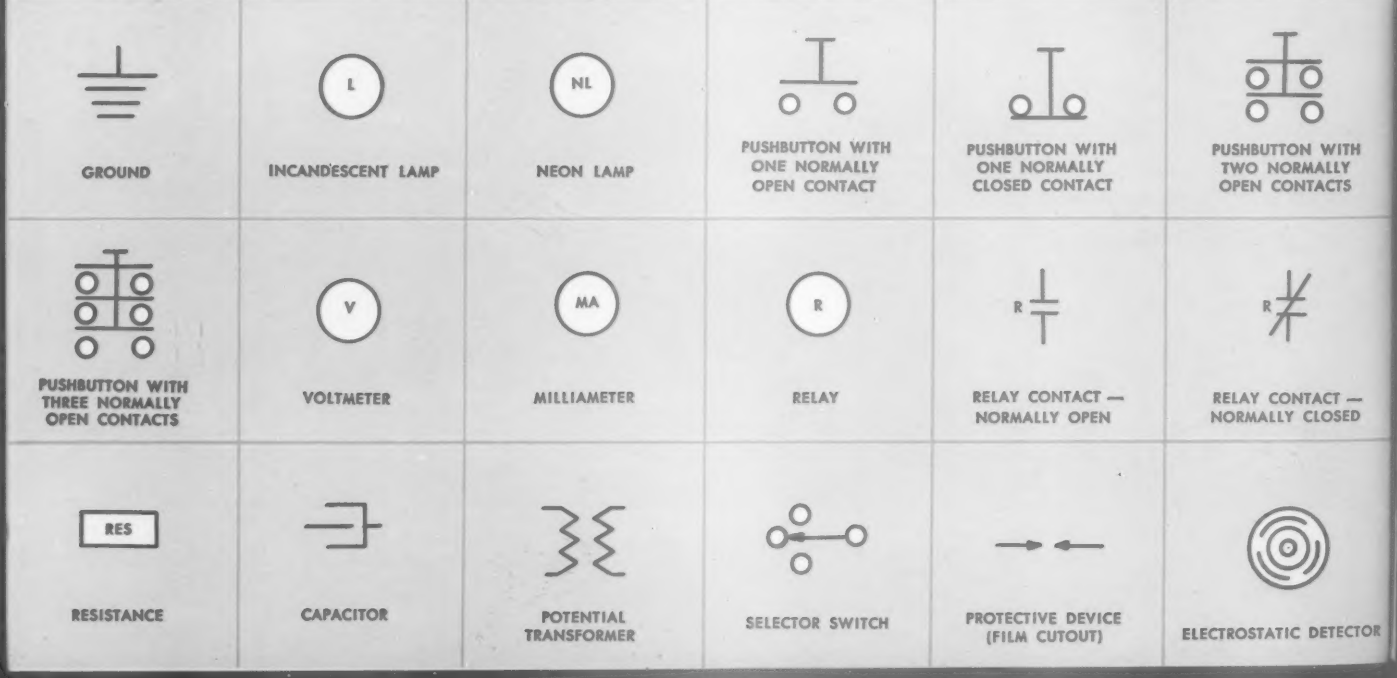
Systems for ground detection vary greatly in cost and complexity, depending upon the amount of information required; the reliability and type of system and the number of phases, if alternating current is involved. Good engineering requires that such schemes be kept as simple as possible, with the number of parts kept at a minimum.

Past and present practice prompts the use of two or more lamps or voltmeters to show the magnitude of line to neutral voltages. Presence of a ground is noted by an indicated unbalance of these voltages. The degree of unbalance also shows how solid a ground is. Many grounds, of course, start with relatively high resistance and, with time, progress to much lower values.

An alarm scheme of ground detection will enable an operator to predetermine, in effect, the degree of accidental grounding that can be tolerated. In some cases this can be valuable. Another factor in determining the choice of a method of ground detection for any particular installation is the amount of supervisory operation at the point where the detector is installed. In unattended locations it may be, and often is, very desirable to use a system with alarm provisions. The alarm should be remotely located from the detector but in such a place that the attention of operating and maintenance personnel can be attracted by it as soon as trouble occurs. The remote alarm would, of course, not indicate the phase or polarity involved. This information would be given by the lamps or meters at the detector.

The accompanying drawings show most of the common methods and some of the more uncommon ones used for ground detection. These are listed in accordance with the type of power system first and the method second. Symbols used in Figures 2 to 5 are given in Figure 1.

LIST OF SYMBOLS used in diagrams in Figures 2 to 5. **(FIGURE 1)**



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WISCONSIN

Detecting d-c grounds

Figure 2 shows some of the many schemes for direct current systems. Examples (a), (b), (c), and (d) utilize two lamps. The lamps must be good for the total line-to-line voltage and ordinarily will glow with very subdued brilliancy unless a ground is on the system. The midpoint between lamps is grounded either solidly or through a pushbutton. In (a), a ground is indicated by one lamp being dark and one being bright, the dark lamp being on the grounded polarity. In (b), when the button is depressed, one lamp will be dark and one bright if a ground exists. Scheme (c) is like scheme (a) except that depressing the button with a ground on either polarity will cause both lamps to glow dimly and serve as a check on the lamps. In (d), a double contact button is used and ordinarily the lamps are dark.

Methods (e) and (f) use voltage relays. Without a ground on the system both relays have equal voltages. In (e), the relays are overvoltage relays and the relay connected to the ungrounded line will then receive line-to-line voltage, close its contacts and ring an alarm. With (f), the relays are undervoltage relays and the relay connected to the grounded line will lose its voltage, close its contacts and ring an alarm.

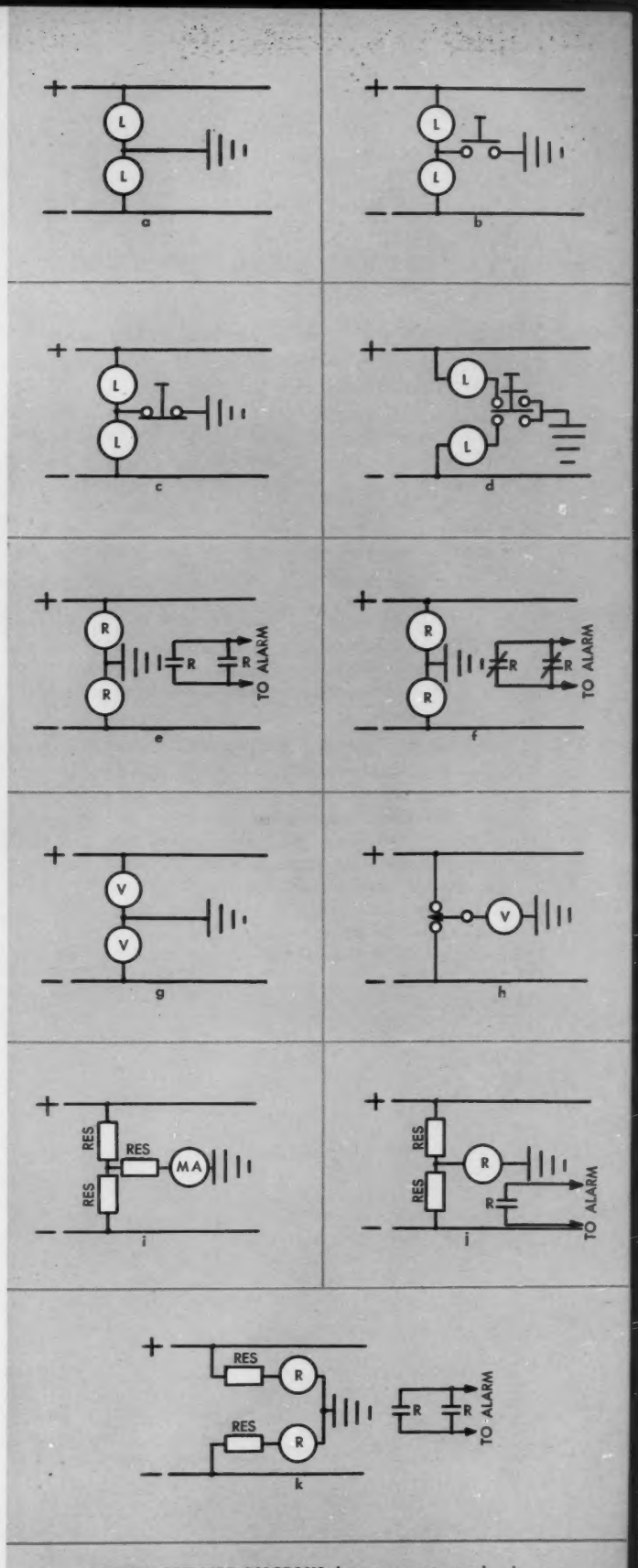
Voltmeters are used in (g) and (h). In (g), they normally read half of line-to-line voltage. With a ground on either line, the voltmeter on that line will have its reading decreased and the other will have its reading increased. With (h), if the switch is in the center position, no reading is obtained. With the voltmeter connected to either line in turn, a ground will be indicated as before by one reading being lower than the other.

Scheme (i) uses a milliammeter to detect a flow of ground current but does not indicate the polarity grounded. The meter must be protected against excessive current and the resistor shown in series with it must be large enough to limit the current through the meter to a safe value.

Methods (j) and (k) utilize current sensitive relays. Scheme (j) is similar to scheme (i) except that now the relay contact will close if a ground exists and gives an alarm. It will not indicate the grounded line. Scheme (k) uses two similar current relays with their contacts in parallel to give an alarm. The pickup point for the relays must be less than the current that normally will flow through the two in series when no fault exists. The relay connected to the unfaulted line will close its contacts and ring the alarm.

Lights and alarm detect a-c grounds

Figure 3 shows ground detection systems for single-phase alternating current system. Systems (a) through (k) are like those for direct current and the comments given will likewise apply. Schemes (l), (m), (n), and (o) utilize static capacitors for coupling devices and as voltage dividers instead of resistors. In method (l) a milliammeter will indicate the existence of a ground but will not show the grounded line. Scheme (m), which is similar to (l), has two neon bulbs which indicate the grounded line, the one connected to the dark bulb. The bulb on the ungrounded line will have full brilliancy. With method (n), a situation similar to (l) exists with the exception having substituted a current sensitive relay for the milliammeter. The relay contact will now give an alarm but, like (l), will not show the faulted line. In (o), as in (m), neon bulbs have been added. This arrangement will



GROUND DETECTOR DIAGRAMS shown represent several variations suitable for low voltage, direct-current installations. Applications are the simplest for this type of system. **(FIGURE 2)**

not only give the alarm but indicate by a dark bulb the line in trouble.

Figure 4 extends the connections and methods of Figure 3 to apply to three-phase low voltage alternating current systems and the comments applying to the schemes of Figure 3 follow for Figure 4.

High voltage detectors need extra units

Figure 5 represents methods applicable on three-phase alternating current systems over 600 volts. Methods (a), (b), (c), (d), (e), (f), (g), and (h) are similar except for the addition of potential transformers to those described for low voltage systems. Potential transformers should have primary windings with ratings equal to the line-to-line voltages and secondaries of 120 volts. Scheme (i) shows a system wherein the secondaries are connected in delta with an overvoltage relay closing one corner of the delta. Normally, if no ground exists, the three secondary voltages will add up vectorially to give zero voltage. A ground on any line will cause the corresponding secondary voltage to disappear and the relay will then have 208 volts impressed upon it and will then close its contacts sounding an alarm. If desired, lamps may be put across each transformer secondary to indicate the grounded phase.

Systems (j) to (n) utilize capacitor coupling instead of potential transformers. All but (n) are similar to those for low voltage systems except for the added protective devices which may be film type cutouts, as used on series street lighting circuits, to protect the meters, relays, etc., in case of capacitor failure. Method (n) is the common electrostatic type wherein voltages from three coupling capacitors are applied to three fixed vanes. A movable, centrally located vane is ordinarily held by electrostatic attraction in a center position, but if a ground occurs this movable vane will then move away from the fixed vane connected to the grounded phase.

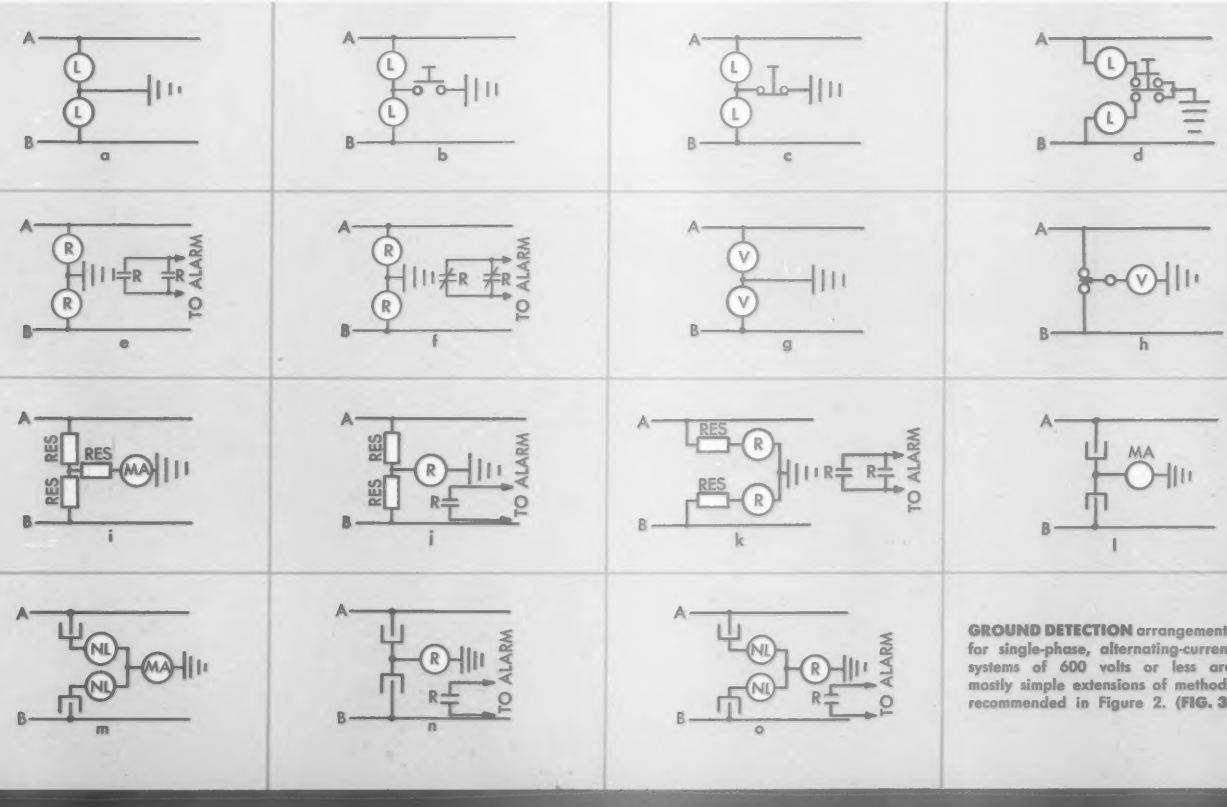
System determines detector scheme

These schemes are arranged according to type of power system and number of phases and illustrate the many possible combinations of equipment that can be used to detect grounds on normally ungrounded systems. A great variety of schemes exists and ingenuity will suggest possible variations of those shown here. A choice should be based upon whether or not an alarm must be given. If so, the choice is automatically restricted to a system using a relay, either current, or voltage as the particular arrangement requires.

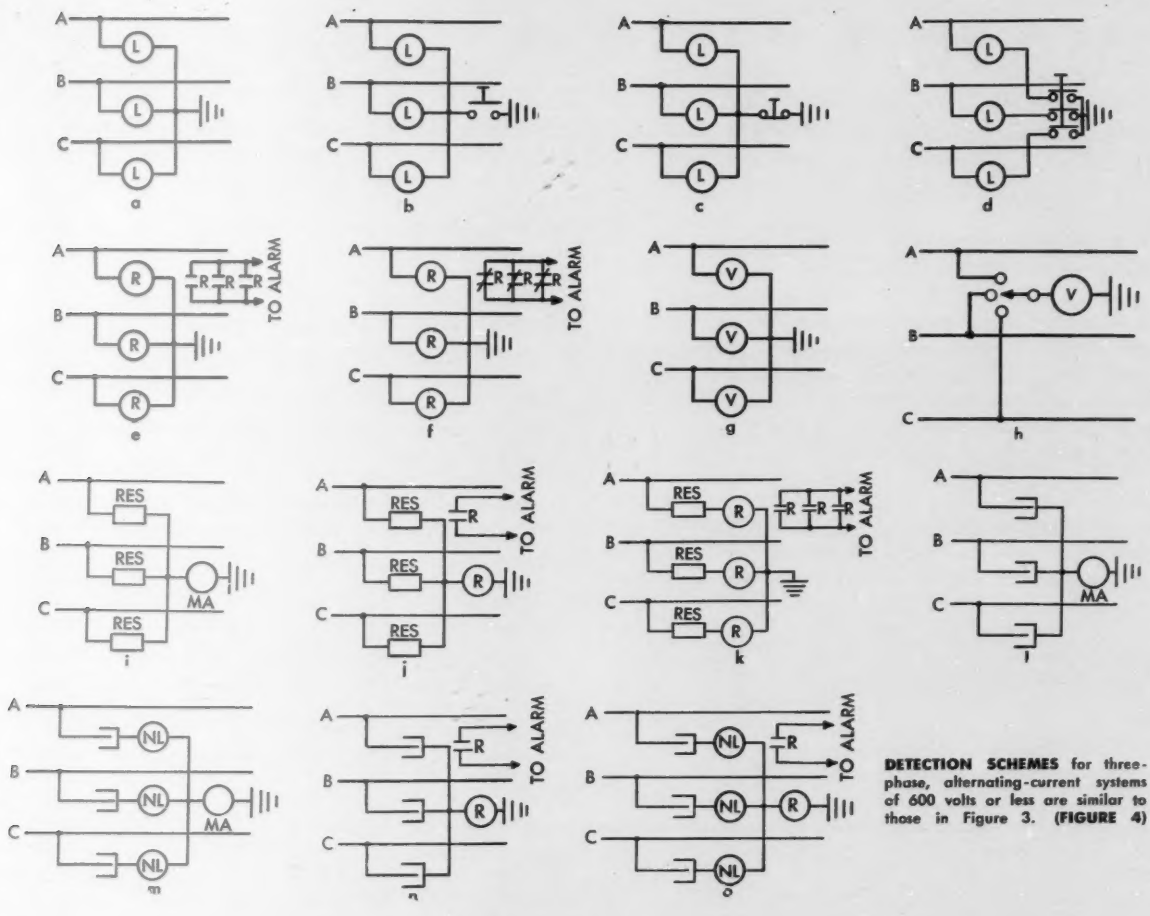
It is also desirable to have some method of showing the phase that is in trouble. This can be given by lamps or voltmeters. The lamps have the disadvantage of possibly burning out and giving erroneous results. Voltmeters give a more accurate indication of the degree of grounding existing than do lamps and if the amount of money to be invested is not too important, they are highly desirable in any ground detection scheme. Standard voltmeters may be used but special scales are available marked to indicate the voltage range of the ground on the system. The electrostatic detector has the disadvantage of having all of its parts subject to rather high potentials so that personnel must be carefully protected from accidental contact with its live parts.

Coupling capacitors shown in some of the schemes may be standard capacitors or they may be a layer of foil embedded in a standard section of bus insulating tubing.

These schemes present a wide selection of choices which should prove helpful in determining the method and apparatus for a ground detector. Some of the schemes have obvious shortcomings, but the foregoing circuits and explanations enable the individual power system operator to arrive at a satisfactory choice for his particular type of system.

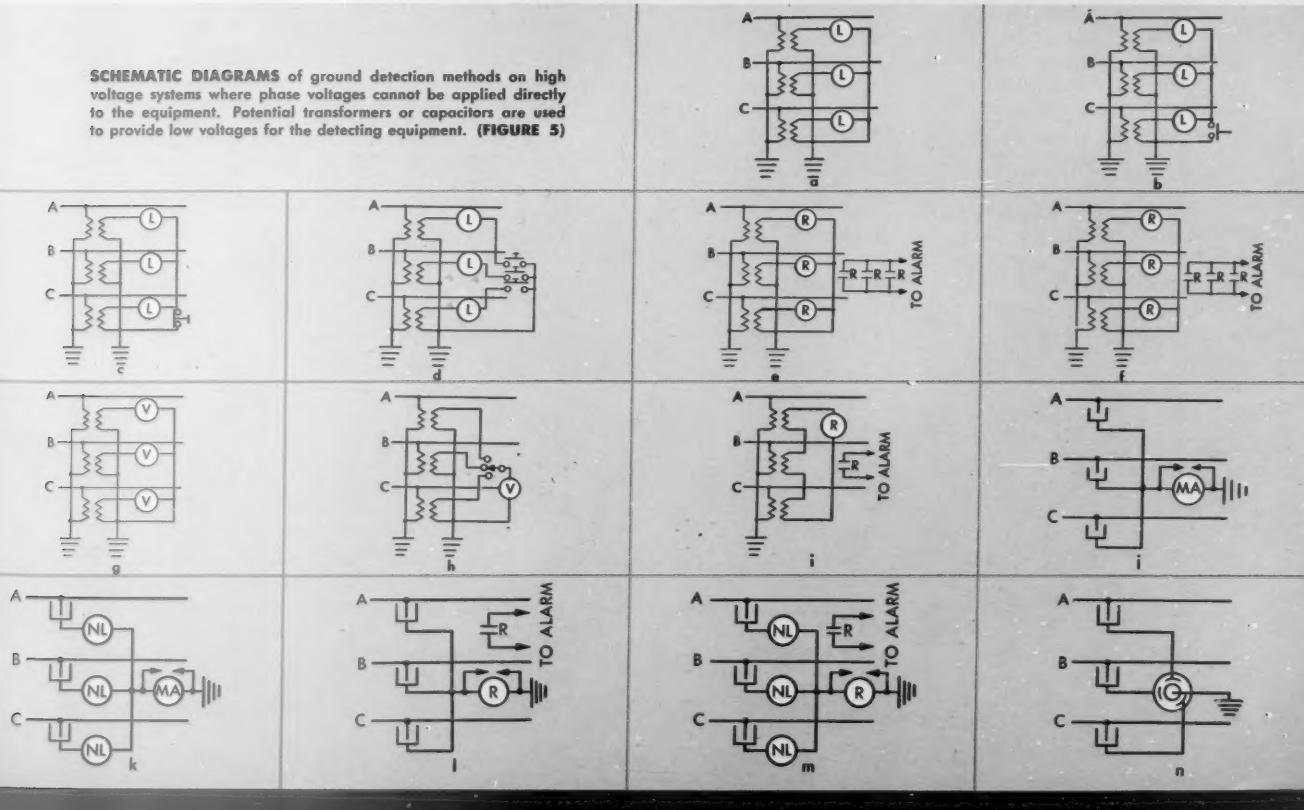


GROUND DETECTION arrangements for single-phase, alternating-current systems of 600 volts or less are mostly simple extensions of methods recommended in Figure 2. **(FIG. 3)**



DETECTION SCHEMES for three-phase, alternating-current systems of 600 volts or less are similar to those in Figure 3. **(FIGURE 4)**

SCHEMATIC DIAGRAMS of ground detection methods on high voltage systems where phase voltages cannot be applied directly to the equipment. Potential transformers or capacitors are used to provide low voltages for the detecting equipment. **(FIGURE 5)**



"ONE FOR THE BOOKS"

Grouting

PART FOUR OF FOUR PARTS

LEON A. WATTS
General Superintendent
Service and Erection Department
Allis-Chalmers Mfg. Co.

ALIGNMENT of flexible couplings or gears should be planned to follow one or the other of the two methods described in Part III, or a specifically planned compromise. Flexible couplings will not compensate for misalignment in either the vertical or horizontal plane. A flexible coupling should be aligned as accurately as one that is solid.

Nests of shims should be stacked and wedges and jack bolts set so as to come up tightly and contact the base or sole plate in such a manner that, after the grout has been poured, tamped, and set, the shims, wedges, or adjusting bolts may be removed. Adjusting devices, wedges, or jack bolts must be removed because they would constitute a small area or point of heavy concentrated load if left in. This point of contact will, in time, have been eliminated through the ever present vibration and brinelling action, and may cause the foundation bolts to loosen or possibly cause some misalignment in the equipment. Removing metal point supports permits the load to come down solidly on the broad foundation where it is properly distributed.

Temperature affects grouting

The foregoing applies only to equipment placed on horizontal foundations. Such machines are practically always at ambient temperature and in equilibrium. Due allowances must be made whenever a basic temperature difference, such as 50 degrees basic ground temperature, in contrast to a cold or hot air temperature around the machine is encountered.

Foundations that are not integrally cast and one end of which is subject to ambient or room temperature and the other to a high temperature, such as steam turbine or engine foundations, confront erecting engineers with another set of problems. Induced heat in the steam ends of such foundations adds to the difficulties. It is well known that the coefficient of expansion of concrete and steel is practically the same.

Where one portion operates at room temperature and the other at considerably higher temperature, the rate of heat absorption from conduction and radiation, however, is poles apart. This complex problem should be considered when aligning and grouting heavy machinery. Disregarding the temperature differential in such cases usually results in faulty operation to a greater or lesser degree after grouting. This is especially true in cases of sectionalized foundations, such as turbo-generators having several non-integral foundations, or cement kilns having from two to six separate and distinct foundations with the extreme temperature differential between the feed end foundation and the firing or discharge end foundation.

Even long penstocks and heavy hydraulic equipment subject to solar heat can, in fact, cause serious misalignment due to the temperature differential between day and night. There have been occasions where this type of equipment had to be equalized by water spraying before and during grouting to assure permanent alignment. This relationship between grouting, temperature differential, and final alignment cannot be overlooked when installing equipment. These differences and difficulties can be minimized by stressing proper preparation of grout to meet varying but specific needs.

Jobs vary grout requirements

Generally, grout ingredients should be mixed dry and until the mass is uniform in color. The proper amount of water is then added and the grout mixed constantly for at least 30 minutes before it is placed. Unless a job is too small to justify the expense, a mechanical concrete mixer should be used.

Simple, lightweight grouting can be accomplished with a mix of one part cement, two and one-half parts of clean sand with sufficient water to obtain proper flowability of grout. Local conditions determine the amount of water needed. This mixture is suitable for a grout space up to two and one-half inches. For grout space in excess of three inches, three and one-half to four parts of clean gravel should be added to the mortar mix. Anything over six inches may use one inch river stone or one inch crushed stone to replace gravel. Again, the water content should be governed by actual requirement, bearing in mind that the shrinkage of grout or concrete is chargeable to the loss of water which is bled from the grout after it is placed. Keep water as low as possible under all conditions, without impairing flowability. Shrinkage can also be reduced by reworking the grout after the initial set, allowing 30 to 40 minutes before reworking. Reworking is possible in only a few cases. Under no circumstances should grout be reworked if it contains any ingredients used to overcome grout shrinkage.

Where grout areas are not over two and one-half inches high and water content has been properly controlled and held to a minimum, trouble from shrinkage will not develop. The actual contact area under a sole plate or pedestal is comparable to a flat thrust bearing or a cylindrical or bushing type bearing, i.e., around 75 percent contact of the pedestal or sole plate on the grout. These contact areas should be numerous and well distributed.

For heavy, concentrated loading, a mix of one part cement, one and one-half parts clean sand are adequate for vertical grout space up to and including two and one-half inches. Anything over this requires a mix of one part cement, one and one-half parts graduated sand and three parts of 3/8-inch pea gravel, or its equivalent of crushed stone. A good concrete foundation may be obtained by mixing one part cement, two parts sharp sand and four parts of 1½-inch washed stone. In nearly all cases, there is a tendency to use too much water, and since the water content is vital it should be given special attention when mixing either grout or concrete. A quick check can be obtained by using an ordinary galvanized iron pail. Pail should be filled with grout mix and upset on the floor and pail removed. A settling of over two inches means that more water is present than is required for maximum strength.

Is It Weight - or Mass?

WALTHER RICHTER
Engineering Development Division
Allis-Chalmers Mfg. Co.

Weight is weight and mass is mass . . . and that's all there's to it.

PEOPLE, engineers included, who live in glass houses shouldn't throw stones! Engineers who are proud because they deal with factual sciences sometimes laugh at the confusion found in the fields of economics, politics, and sociology, but this business of engineering has a few skeletons rattling in its closets which should take the wind out of any engineer's smug chortling in jig time.

Perhaps no other single subject in the field of engineering is the source of more confusion than the one dealing with the relations between mass, force, and weight. Not a day passes that somewhere an engineer, looking incredulously at his calculations, realizes that he has forgotten to divide or multiply by 32.16 somewhere along the line. This seems to be all the more incredible when one considers that all the necessary information dealing with the subject is completely covered in any book on mechanical engineering. In view of this fact, it may seem superfluous to devote any additional space to the matter, but since undeniably confusion does exist, the attempt to throw some additional light on it with the aid of a somewhat unorthodox presentation may be justified. Could be that it may clear away some of the confusion. Then again, it may make it worse.

Once upon a time—

Suppose that some sunny day a space ship from a hitherto unknown planet landed on one of our air fields. The unearthly visitors emerging from it, having beaten us in the race of interplanetary travel, can be assumed farther developed mentally than we are and, consequently, will find many of our earthly customs amusing and quaint, to say the least.

There would, of course, be a tour of inspection of the earth and an introduction to the wonders which earth men have wrought. The guests would return the compliment by inviting representatives of the various sciences to accompany the visitors to their planet and unfold for them the wonders of earthly "know how." The brain trust finally selected for this exciting voyage would include a doctor, lawyer, mathematician, physicist, and, after a long debate, an engineer.

Naturally, representatives of the natural sciences, the physicist and the engineer, would like to take along their units, or standards, so they will avail themselves of exact replicas of these standards. Engineers and physicists agree that only three fundamental units are required from which all others may be derived.

Units foster differences

They also agree that length and time should be two of the fundamental units, but, as shall be seen shortly, they do not agree on the choice of the third. To demonstrate his unit of length, a British or American engineer would take along a replica of a rod preserved in London, called a foot. If the engineer would be from continental Europe, he would get himself a duplicate of a rod preserved in Paris, called a meter. The physicist will take along a much smaller rod to demonstrate his unit of length, called a centimeter, namely, one hundredth the length of the rod taken along by the continental engineer.

All the engineers and physicists have agreed upon the unit of time, one second. This is the 86,400th part of the time it takes the earth to make one complete revolution. To demonstrate it, a good chronometer must be taken along.

For the third fundamental unit the representatives of the engineering profession have chosen that of force. The unit of force chosen by the British or American engineer is one pound, while the unit of force of the continental engineer is one kilogram. Well, what is this pound or kilogram? Is it the force with which some legendary king could pull on some specified bow, or is it the force which a wind blowing with a certain specified speed exerts against an area of one square foot?

Everybody knows, of course, that the units of force used by the engineering profession are the forces with which the earth pulls on certain pieces of material preserved in London (for the British or American engineer) or in Paris (for the continental engineer), from now on designated herein as the CHUNKS, and *not* as "one pound" or "one kilogram." To the engineers "pound" and "kilogram" do not refer to the CHUNKS themselves, but to the pull of the earth on them.

If the engineers would hang their respective CHUNKS on a plain helical spring, such as found in a fish scale, and mark the points to which it would deflect under the pull exerted on their CHUNKS by the earth, they would have another means of demonstrating their respective units of force. Whenever the spring would be extended to the previously marked points, it would exert a force of one pound or one kilogram, respectively.

The engineering representatives, therefore, wrap up their two CHUNKS for their trip to the unknown planet. If they are as smart as they pretend to be, they would do well, however, to take along also the calibrated spring just mentioned.

Force versus mass

The physicist does not agree with the engineers in the choice of the third fundamental unit. Instead of choosing *force*, as the engineers did, he chooses *mass*. Let it be clearly understood that this is not just a difference in the *amount* of units, but a difference in the *nature* of the unit. A foot and a meter may not be equal, but they are both of equal nature, namely, they represent length. One can be converted into the other, when the conversion factor is known. But a foot and a second are quantities of an entirely different nature; one can never be converted into the other. In a similar way, mass and force are two quantities of entirely different nature.

It is important to recognize that the two engineering representatives, both having chosen force as the third fundamental unit, agree on the *nature* of this unit even if they propose different *amounts* for it. The physicist has chosen mass as the third unit, which is altogether different from force.

To demonstrate his unit of mass, the physicist takes along a little chunk which he calls a gram. To be exact, a thousand of his little chunks would amount to as much as the CHUNK of the continental engineer. If made of steel, his chunk would be a small cube with each side about one-fifth of one inch long.

The engineers and the physicists are seen to set out on the trip each equipped with a rod, a chronometer, and a piece of material. If any difficulty were to be encountered by one of them with this kind of set-up, it would appear that it will most certainly also be faced by the others. There is, however,

all the difference in the world in the meaning and in the purpose of the pieces of material taken along by the engineers and the physicist. The engineers take theirs in the hope of demonstrating their idea of force, while the physicist takes his pellet along as a means of demonstrating his unit of mass.

Gravity upsets demonstration

Safe and sound on the imaginary planet, which happens to be much smaller than the earth, perhaps as large as the moon, the scientists begin to prepare for their lectures and demonstrations.

It should be obvious at this stage that the engineering representatives will be in trouble when it comes to demonstrating their unit of force. One the smaller planet, gravity does not pull as hard on the CHUNKS they brought along as it did on earth. A silk thread, for instance, which might have broken under the pull of one of them down on earth, will now be able to support many of these CHUNKS. Consequently, the choice of the engineer to tie up his unit of force to the gravitational pull of the earth does not seem to have been a very wise move. But while it may not have been too wise, the reasons leading to it are understandable.

The bridge builder and the architect must design their structures essentially to support loads on which gravity acts. An engineer designing a crane or an elevator has also to overcome the forces of gravity. In contrast to this, the force exerted by a compressed spring, by an expanding gas, or by a conductor carrying an electric current and disposed in a magnetic field has nothing to do with gravity. The engineers would have been much better off had they left their respective CHUNKS at home and brought along only the spring scale, calibrated with the aid of the two CHUNKS before they had begun the trip.

Mass is er—ah—?

What of the physicist? He exhibits his little pellet which he brought along as his unit of material or mass. What are the characteristics of mass? For an answer one hears occasionally that it has "weight." But "weight" is nothing more than a short expression for "the pull exerted by gravity on a mass."

It is true that when a mass is brought into a gravitational field, a force will be exerted on it, that is, it will exhibit "weight." However, a pound of butter certainly does not cease to be a pound of butter (and becomes, perhaps, margarine) if it should be brought to a point in interstellar space, where the resulting gravity is zero.

Newton, who pondered upon this question, gave the following answer: the characteristic feature of mass is inertia. He stated that the application of a force to a mass which is free to move in the direction of the applied force, will result in a change of speed of the mass, or acceleration.

He also studied the relation between the force applied to a given mass, and the acceleration resulting from this application. He found that the resulting acceleration was proportional to the force acting on the mass, and inversely proportional to the mass itself. This results in the well known formula:

(1) $\text{Force} = k \times \text{mass} \times \text{acceleration}.$

It is this relation which the physicist, as well as the engineer, employs for the derivation of his unit of force (or mass, respectively) from his original three fundamental units. Since they both desire to have their relations as simple as possible and since they are entirely free in the choice of how large or small their fourth unit should turn out, they both strive to define it so that the proportionality factor "k" in the above equation turns out as unity. This means then that equation (1) simplifies to equation (1a):

$\text{Force} = \text{mass} \times \text{acceleration}$

It will be remembered that the physicist brought his little

pellet, the gram, along for the purpose of showing his unit of mass; according to equation (1a), his unit of force will, therefore, be the one which will impart to his unit of mass, i.e., one gram, the unit of acceleration, or one cm/sec^2. To give his audience a notion about the size of his unit of force, he places his little pellet on a well-oiled, level surface and pushes it just hard enough to make its speed increase by one cm/sec every second. The force or push needed on the pellet to bring about this result is called one dyne. It has absolutely nothing to do with gravity and will turn out in exactly the same amount regardless of whether the experiment is carried out on the earth, or on the imaginary planet, or even in interstellar space (where on a spot of zero gravity, our physicist could dispense with the well-oiled surface altogether).

Engineers derive mass

Back to the engineers now, who, after a hasty conference, have decided to put their two respective CHUNKS (the pound and the kilogram) into their traveling bags, never to speak of them again. The calibrated helical spring, which they were smart enough to take along, will be used to demonstrate their unit of force. It will now be up to the engineers to derive their units of *mass* from their units of length, time, and force, just as the physicist had derived his unit of *force* from his units of length, time, and mass.

Also making use of Newton's findings, the engineers, just like the physicist, would like to choose their units of mass in such a way that the proportionality factor in equation (1) comes out as unity. Consequently, their unit of mass will be possessed by an amount of material which will show unit acceleration (one ft/sec^2) when acted upon by their unit of force. The latter can be accomplished by pulling on the mass with the aid of the calibrated spring in such a way that the pointer is just pointing to the respective calibration mark. The engineer, therefore, will place a block of material — either rock, wood, or metal — on a well-oiled, horizontal surface and increase its amount until it shows an acceleration of one ft /sec^2 (or one meter/sec^2) when pulled on with a force of one pound (or one kilogram), as applied through the calibrated spring.

How big a chunk of material will this turn out to be? How will it compare in size with the CHUNKS which the embarrassed engineers were putting back into their traveling bags?

We know that down on earth the pull of gravity acting on the British engineer's CHUNK would cause it to accelerate with 32.16 ft/sec^2. But the spring, when the pointer is at the one pound mark, pulls just as hard as gravity does on earth. Consequently, if he were to pull with this calibrated spring on the CHUNK which he brought along from the earth, provided the surface was horizontal and well oiled, he would attain an acceleration of 32.16 ft/sec^2. If he only wants an acceleration of one ft/sec^2, while still pulling with the same force, he must, according to Newton, make the block mentioned above 32.16 times as large as the CHUNK in his traveling bag. *This block will then possess the unit of mass for the British engineer, because the application of one pound force to it will result in an acceleration of one ft/sec^2.*

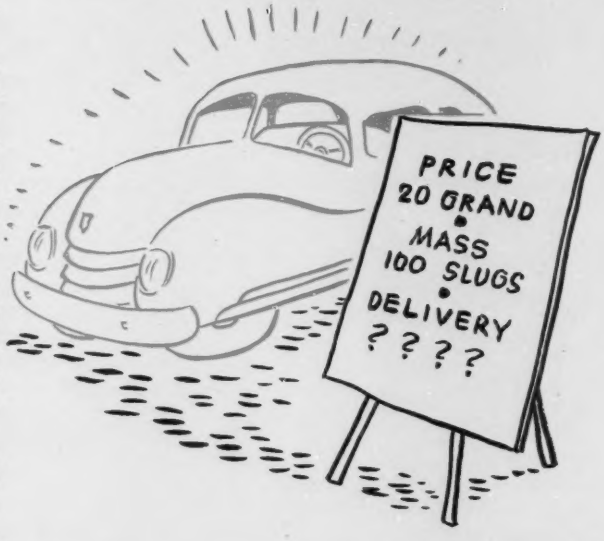
Remember now that the unit of mass is a block containing 32.16 times as much material as the CHUNK preserved in London. Should anyone want to know how much mass an automobile weighing, say, 3,216 pounds has, he must determine how many of these unit blocks of mass it represents; naturally it will be the weight divided by 32.16, or 100.

It has just been stated that the mass of the abovementioned automobile is 100. Somebody might ask: "100 what?", a difficult question to answer since the unit of mass does not have a name, or at least not one that is generally accepted. Nobody can say that it has a mass of 100 pounds, because everyone knows that it weighs 3,216 pounds! To use the same name for two entirely different quantities is certainly a dastardly thing to do, but that is exactly what engineers are doing!

A name has been proposed. The engineering profession should adopt it generally; the name is "slug." Then it could be said that the automobile in question has a mass of 100 slugs. It is evident that the mass of any material, in slugs, will be equal to its weight divided by 32.16.

Metric system also has drawbacks

The metric system used by the continental engineer is up against exactly the same trouble. The continental engineer also wants to have the relation expressed by equation (1)



come out in such a way that the proportionality factor "k" turns out as unity. In order to accomplish this, he must choose his unit of mass in such a way that a force of one kilogram will produce an acceleration of one meter/sec^2. This turns out as a block containing 9.81 times as much material as the CHUNK preserved in Paris. As a matter of fact, the poor man is even worse off than the British or American engineer, because no name has even been suggested for his unit of mass, much less been accepted!

It should be clear by now that the CHUNKS preserved in London and Paris (one pound or one kilogram) are for the engineer strictly a vehicle to define, via gravity, his unit of force. But in his system the unit of mass is a derived one, and has nothing to do with the CHUNKS. It is not very

hard, however, to find books in which the CHUNK in London is referred to as the "standard of mass." It is this attempt to make the CHUNKS serve two purposes which causes the unholy confusion. As seen, it plagues the foot-pound system and the metric engineering system equally hard.

Note that the physicist has escaped this trouble completely; when he speaks about 15 grams, he never means a force (otherwise he would talk about dynes) but he means a certain amount of material. When, on the other hand, an engineer speaks of 25 pounds, he should by right only have a force in mind, but he often uses the same term to describe the amount of material involved, in which case he should be talking about slugs. But who can criticize him, when he finds a statement in his books that the pound preserved in London is the standard of mass?

Standard and unit differ

There is a way of wriggling out of this predicament, however. The term "standard" does not necessarily mean the same as "unit." Thus, for the electrical engineer, for instance, the standard of voltage is usually a Weston cell. But its voltage is by no means the unit of voltage. When the ratio between the standard and the unit are known, the unit can be constructed out of the standard. Therefore, the statement that the CHUNK preserved in London, called one pound, is the standard of mass does not necessarily have to mean that it is also the unit.

Slug would solve problem

The unit of mass for the engineer is seen to be constructed by taking 32.16 of the standards. If engineers, whenever they meet the expression "mass," would try to visualize a block of material 32.16 times as much as the standard mass preserved in London, this bigger block being marked "unit of mass" or "one slug," many of the difficulties would undoubtedly disappear.

There is another system of units in which the piece of platinum preserved in London serves as the *unit* and not merely as a *standard* of mass. A man having adopted this system would take the CHUNK along on his interplanetary trip, not as a means of demonstrating his unit of *force,* but as his unit of *mass.* He differs from the engineers in precisely the same way as the physicist did, since he has chosen length, time, and mass as his fundamental units and not force, as the engineers had done.

Just as the physicist derived his unit of force as the one which would give his unit of mass the unit of acceleration, so the man using the pound preserved in London as the unit of mass will derive his unit of force as the one which will impart to the CHUNK called a pound an acceleration of one ft/sec^2. This force is called a poundal. On a spring scale, a poundal would be equivalent to approximately one-half ounce.

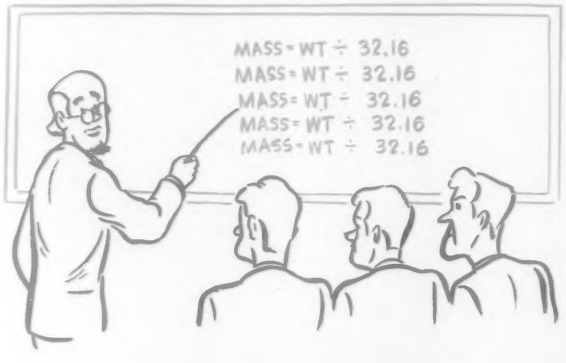
This force can be arrived at in the following manner: a pull on the CHUNK in London with a force registering one pound on a spring scale (force is the same as that exerted on the CHUNK by gravity) results in an acceleration of 32.16 ft/sec^2. Consequently, if an acceleration 32.16 times smaller is desired, a correspondingly smaller force would be needed. And since there are 16 ounces in a pound, this would equal approximately one-half ounce.

The system has not been widely applied, but it is perfectly logical and consistent for anyone acquainted with it. Its chief shortcoming is the smallness of the unit of force which would lead to large and cumbersome figures when expressing forces ordinarily encountered in engineering calculations.

The physicist's unit of force, the dyne, is very much smaller than either the pound or the poundal. A million dynes equal roughly two pounds. There is no reason why engineers, if they adopted the units of the physicist, could not deal with megadynes. After all, they do use kilowatts, megawatts, and microfarads.

Mass and force clarified

The difficulty with the systems of units used by the engineering profession arises therefore from the fact that the purpose



and the meaning of the CHUNKS of material preserved in London and Paris are confused. In engineering, their weight, that is, the pull of gravity on them is the only thing of importance, since it represents the unit of force which the engineer uses. As long as the engineer wishes to preserve the proportionality factor unity in the formulas "force = mass × acceleration," these CHUNKS *cannot possibly serve simultaneously as the unit of mass.* Unfortunately, the term *pound* is used indiscriminately to describe an *amount of material* such as a pound of butter or a pound of potatoes as well as a *force* such as is exerted by a spring or by a magnetic field on a conductor carrying an electric current. In one case, the term pound designates an amount of material or a mass; in the other, it means force only.

The unit of mass for the British and American engineer then is an amount of material 32.16 times as much as that of the CHUNK preserved in London, This is the reason why he has to divide the weight by 32.16, if he wishes to know the number of units of mass in a given amount of material.

Now, is this clear? Or shall we go through it again?

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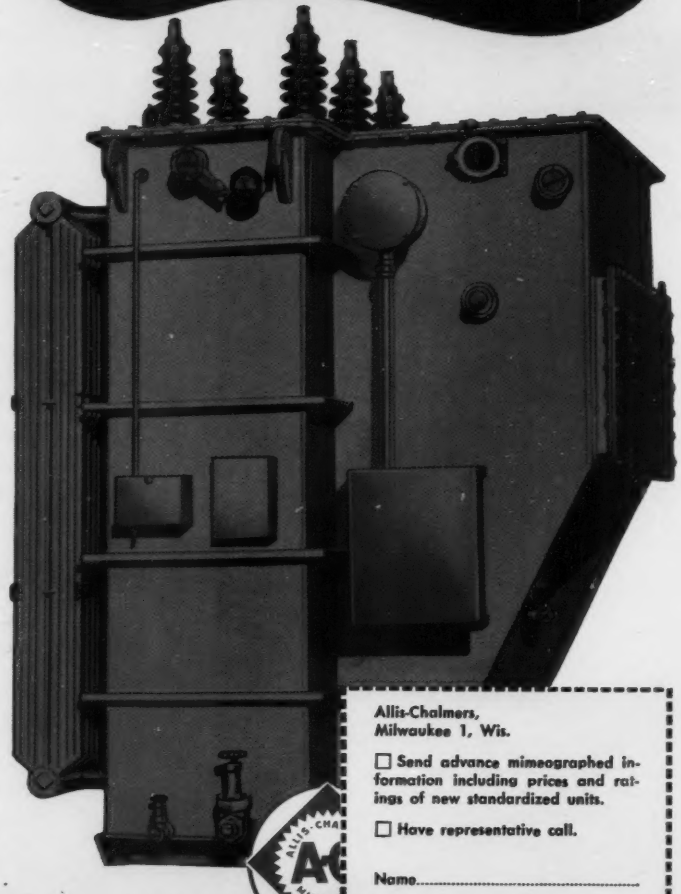

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